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An Enumeration of Research To Determine the Optimal Design and Use of Army Flight Training Simulators

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This document lists and describes research the authors judged necessary to determine the optimal design and use of Army flight training simulators. Two major lines of research are described; the first addresses the design fidelity issue. Specifically, research is described that is judged necessary to determine the most cost- and training-effective level of fidelity for four simulator components: the visual system, the motion systems, the math models that determine the handling qualities of the flight simulator, and the cockpit
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displays and controls. The purpose of the second line of research is to determine how best to use production simulators that have been or are soon to be acquired by the Army. This line of research focuses primarily on the use of production simulators for field unit aviators who have completed institutional training and have been assigned to an operational field unit. However, the second line of research addresses some issues associated with the use of flight simulators for institutional training at the U.S. Army Aviation Center received before the aviator's first assignment to an operational unit. keywords:

This document was prepared to serve as a vehicle for initiating meaningful dialogue among the agencies and personnel who share responsibility for optimizing the benefits of the Army's Synthetic Flight Training System (SFTS) program; it has not been officially endorsed by any Army agency.

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An Enumeration of Research To Determine the Optimal Design and Use of Army Flight Training Simulators

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Training and Simulation

FOREWORD

The Army is committed to the use of flight simulators to augment the training that Army helicopter pilots receive in the helicopter itself. The most important reasons for this commitment are discussed in the main body of the report. For now, it is sufficient to say that the use of flight simulators to augment aircraft training is the only means, during peacetime, of achieving the level of operational readiness that is desired at an acceptable cost. Until now, nearly all the resources expended by the Army on its Synthetic Flight Training System (SFTS) program have been aimed at hardware development and acquisition. The resources devoted to research on how best to use flight simulators is miniscule by comparison. Hence, it is not surprising that there are a large number of uncertainties about the specific role of flight simulators in the Army's aviator training program. It is worth noting that these uncertainties are not unique to the Army; both the Air Force and Navy are faced with much the same problem.

In preparing this document, the authors and contributors attempted to be thorough in identifying critical research issues. Also, to the extent possible with the time and resources available, an attempt was made to develop research plans that address the issues in a meaningful and practical way. We feel confident that the research issues identified are important and relevant. However, we do not consider the research plans presented in this document to be the only way or necessarily the best way to deal with the issues identified. When developing long-term research on a topic about which so little is known, it must be expected that the results of earlier research may drastically change one's early views about the best way to proceed. In short, the plans for later stages of the research must be considered tentative and subject to change, based upon the findings of earlier research.

It can be argued that plans for research on such a difficult topic should proceed in a step-by-step fashion. Indeed, this approach is much less threatening to the research planner who must formulate projects based on premises several levels removed from any empirical data. Also, this approach is less likely to portray to decision makers a research requirement that initially appears overwhelmingly complicated and costly. The disadvantages of the step-by-step approach, which we feel far offset the advantages, are twofold. First, a great deal of time and research continuity would be lost if efforts to obtain funding and administrative support for the next research stage were not commenced until the results of the preceding stage have been fully analyzed and documented. A hiatus between each stage of research would probably serve to make a difficult job impossible. Second, a general notion of the scope of the research is needed to make sensible decisions about whether or not to embark on the research and, if an affirmative decision is made, to make sensible decisions about how best to marshal the resources needed to continue the research until truly useful results are in hand. For these reasons, we have decided that relatively detailed long-term plans--even imperfect ones--serve an important purpose.

The intent is that this document serve as a beginning of dialogue among the agencies and personnel who share responsibility for optimizing the benefits

of the Army's SFTS program. It is hoped that this dialogue, in turn, will lead to the refinement of ideas, to the establishment of research priorities, and to joint planning by all involved agencies. It is important that the reader keep in mind that this is not a document being submitted for approval or disapproval, in total or in part. For this reason, feedback from readers about flaws in the premises and/or reasoning are welcomed. Comments should be sent to Mr. Charles A. Gainer at the following address:

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AN ENUMERATION OF RESEARCH TO DETERMINE THE OPTIMAL DESIGN AND USE OF ARMY FLIGHT TRAINING SIMULATORS

EXECUTIVE SUMMARY

The purpose of this document is to identify the types of research needed to determine the optimal design and use of Army flight simulators. Two complementary lines of research are described and discussed. One line of research--referred to as the "Long-Term Path"--focuses primarily on simulator design issues. The primary focus of the second line of research--the "Short-Term Path"--is the determination of the best way to use the flight simulators that have been or are soon to be acquired by the Army.

LONG-TERM PATH

The general objectives of the Long-Term Path--formulated by the Assistant Secretary of the Army for Research, Development, and Acquisition--are as listed below:

- design research that will yield the data needed to quantify the relationship between fidelity (in selected flight simulator design parameters) and training transfer (for selected flying tasks),

- design research that will yield the data needed to define the relationship between flight simulator production costs and required fidelity in the selected flight simulator design parameters, and

- design research to define the type, cost, and effectiveness of alternate training methods and media that could be used in lieu of flight simulators to train one or more of the selected flying tasks.

In response to the general research objectives, requirements for research were defined for five "primary" research areas and nine "supportive" research areas. The primary research areas are these:

- fidelity requirements for visual system,
- fidelity requirements for motion system,
- fidelity requirements for simulator handling qualities,
- fidelity requirements for cockpit displays and controls, and
- requirements for simulator Instructional Support Features.

The supportive research areas are topical areas in which there are problems or uncertainties that must be resolved in order to conduct effective research in the primary research areas. Supportive research areas identified and discussed include the following:

- flying task data base,
- team/combined-arms training methods,
- performance evaluation,

- alternative training media,
- subsystem standardization/modularization,
- research methodology,
- skill decay/maintenance,
- implementation/monitoring of simulator training, and
- cost-effectiveness analysis models.

The discussion of each of the above research areas includes a description of the research issues and objectives, comments about relevant research that has been reported in the literature, and a description of the research considered necessary to resolve the issues. The research plans vary widely in detail and complexity.

SHORT-TERM PATH

The Short-Term Path is a program of research that is aimed at evaluating and optimizing the use of the family of flight simulators that the Army already has acquired or has contracted to purchase. Since the design of this family of simulators is more or less fixed, the research is focused mainly on determining how best to use the devices: Who should be trained? What tasks should be trained? How much training should be administered? What training methods should be employed for each training application? A secondary objective of the Short-Term Path is to identify design modifications (hardware and/or software) that will improve the training effectiveness of production simulators without incurring excessive product improvement costs.

Three major research efforts are described. The objective of the first research effort is to determine the optimal use of flight simulators in a unit-training context. (Unit training refers to the training received by Army aviators after they have completed institutional training and have been assigned to an operational unit.) The research is designed to assess the simulator's utility for five different training applications: refresher training, skill sustainment training, skill enrichment training, accident prevention training, and maintenance test-pilot training.

The objective of the second research effort is to evaluate the simulator's utility for training beginning students in the fundamentals of helicopter operation. A three-phase study that addresses both simulator design issues and training methodology issues is described. If the early work supports the feasibility of the concept, transfer-of-training studies will be conducted to determine the optimal mix of simulator training and aircraft training.

The objective of the third research effort is to determine the extent to which Night Vision Goggle training can be accomplished in a flight simulator equipped with a visual system.

GLOSSARY OF ACRONYMS

AAA - Army Audit Agency
AFHRL - Air Force Human Resources Laboratory
AGARD - Advisory Group for Aerospace Research and Development
AGL - Above Ground Level
AH - Attack Helicopter
AHIP - Army Helicopter Improvement Program
ANVIS - Aviator's Night Vision Image System
AOI - Area of Interest
AQC - Aviation Qualification Course
ARI - U.S. Army Research Institute for the Behavioral and Social Sciences
ARL - Aviator Readiness Level
ARTEP - Army Training and Evaluation Program
ASI - Anacapa Sciences, Inc.
ASPT - Advanced Simulator for Pilot Training
ATM - Aircrew Training Manual
BOIP - Basis of Issue Plan
CAPTV - Computer Animated Photographic Terrain View
CGSI - Computer-Generated/Synthesized Imagery
CH - Cargo Helicopter
CIG - Computer-Image Generation
CMB - Camera-Modelboard
CRT - Cathode Ray Tube
CTEA - Cost and Training Effectiveness Analysis
DARCOM - Development and Readiness Command
DES - Directorate of Evaluation and Standardization
DLS - Digital Landmass System
DMA - Defense Mapping Agency
DOD - Department of Defense
FLIR - Forward-Looking Infrared
FOV - Field-of-View
FS - Flight Simulator
HUD - Head-up Display
IC - Initial Conditions
IERW - Initial Entry Rotary Wing
IFR - Instrument Flight Rules
IGE - In-Ground Effect
ILS - Instrument Landing System
IMC - Instrument Meteorological Conditions
IP - Instructor Pilot
IPR - In-Process Review
IR - Infrared
ISF - Instructional Support Features
LOD - Level of Detail
MASSTER - Modern Army Selected System Test, Evaluation, and Review

MOPP - Mission Oriented Protective Posture
MTFE - Maintenance Test Flight Evaluator
MTP - Maintenance Test Pilot
NBC - Nuclear, Biological, Chemical
NOE - Nap of the Earth
NTEC - Naval Training Equipment Center
NVG - Night Vision Goggles
OGE - Out-of-Ground Effect
PIC - Pilot in Command
POI - Program of Instruction
PMTRADE - Project Manager Training Devices
RSIS - Rotorcraft System Integration Simulator
SFTS - Synthetic Flight Training System
SME - Subject Matter Expert
STRES - Simulator Training Requirements and Effectiveness Study
TC - Training Circular
TH - Training Helicopter
THIESIS - Training Helicopter Initial Entry Students in Simulators
TOE - Tables of Organization and Equipment
TRADOC - Training and Doctrine Command
UH - Utility Helicopter
USAALS - U.S. Army Aviation Logistics School
USAAVNC - U.S. Army Aviation Center
VFR - Visual Flight Rules
VTRS - Visual Technology Research Simulator

AN ENUMERATION OF RESEARCH TO DETERMINE THE OPTIMAL DESIGN AND USE OF ARMY FLIGHT TRAINING SIMULATORS

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AN ENUMERATION OF RESEARCH TO DETERMINE THE OPTIMAL DESIGN AND USE OF ARMY FLIGHT TRAINING SIMULATORS

SECTION I

INTRODUCTION

BACKGROUND AND OVERVIEW

In June 1982, the Assistant Secretary of the Army for Research, Development, and Acquisition requested that Commander, DARCOM, form a Flight Simulator Steering Group that was to map out the paths future Army flight simulator research and development should take. Gravely concerned about the escalating complexity and cost of simulators, the Assistant Secretary established as the paths' objectives the development/acquisition of only such simulator training capabilities as are absolutely essential and the consequent maximization of simulator training utility.

The initial guidance to the Group was that it provide an appraisal of requirements for determining three issues:

- How much is needed in simulation for effective training transfer?
- What path should development follow to optimize future flight simulator development?
- What Army policies are needed to manage more effectively the simulator program?

The Group's membership was drawn from DARCOM, TRADOC, and the Army Research Institute (ARI) and has represented in it, from both the training and materiel communities, researchers, developers, and managers. This research plan outlines the researchers' and developers' responses to the first two of the Assistant Secretary's issues. Management policies are not directly addressed, but the basic input for policy formulation is provided.

The research plan has three complementary sections: this introduction (Section I) and two proposed integrated research plans (Section II and Section III).

Following this overview, the Introduction operationally defines key terms as they are used in the research plan and then details basic assumptions and concepts that have had a major impact on the formulation of the research plan. Current constraints on flight simulator research and development are then identified and discussed. The introduction is concluded with a statement of the rationale for the two paths of research proposed in Sections II and III.

The next two sections map out two paths of research: a Long-Term Path (Section II) and a Short-Term Path (Section III). The Long-Term Path is aimed at providing comprehensive data for future requirements and at utilizing future technology. Five research areas are identified as the primary domain of the Long-Term Path: fidelity requirements for visual systems, fidelity requirements for motion systems, fidelity requirements for simulator displays and controls, fidelity requirements for simulator handling qualities, and requirements for Instructional Support Features. Secondary areas of required long-term supporting research are also identified. The Short-Term Path is aimed at answering questions about the optimal use of flight simulators that will have been acquired by the Army before the long-term research on simulator fidelity requirements has been completed.

DEFINITIONS

In preparing this research plan, it became readily evident that, across and within different disciplines, a technical term may have slightly or even greatly varying connotations or meanings. Thus, since the research plan is intended for a multidisciplinary audience, it was deemed necessary to posit definitions of certain key terms that are used throughout the research plan.

FIDELITY

"Fidelity" is both the most critical single term in this research plan and the most ill-defined in the area of simulation. It is generally understood and accepted that the term refers to the degree of correspondence between some aspect of the simulator and some aspect of the aircraft or environment, but the nature of the correspondence is at best unclear.

Implicit in the term is the concept that to have full fidelity a simulator must accurately reproduce its real-world counterpart both in form and in function. This view of fidelity, which has been designated "objective fidelity" (AGARD, 1980), arises from the supposition that the most effective training device is the aircraft itself and, thus, the effectiveness of a simulator is a direct function of how well it duplicates the aircraft. This approach, which tacitly considers the simulator a "tethered aircraft," very quickly leads to exorbitant simulator design requirements: as simulator visual systems, motion systems, etc., approach an accurate replication of the real world, cost very rapidly becomes prohibitive.

An alternate, and potentially more economical, view is that fidelity be defined as the degree to which the student <u>perceives</u> the simulator to replicate the aircraft. Termed "perceptual fidelity" (AGARD, 1980), this view arises from the supposition that only those elements of the training environment that can be perceived by the

student need be simulated and that the imperceptible elements may be ignored.

But defining fidelity (and simulator design requirements) solely in terms of elements critical to perception of the simulator as a replication of the aircraft ignores another very important aspect of flight training. A great deal of very effective initial training is conducted in a training environment much different from the operational aircraft. For example, in training helicopter hovering operations, the instructor may retain directional (pedal) control while allowing the trainee altitude and attitude (collective and cyclic) control. Or, the trainee may be instructed, by way of an analogy, to fly a maneuver from one point to another by following an imaginary aerial pathway connecting the two points. Neither of these two examples is "faithful" to the real-world operational environment, yet both are highly effective techniques for training. And both, in a sense, have high fidelity with respect to the trainee's internalized schema or model of flying; that is, they have what might be termed "training fidelity" since they are applicable to the development or to the sustainment of aviators' internalized programs of flying.

So, for purposes of this research plan, any simulator property that is shown to be effective (as defined below) in developing or maintaining flight skills will be operationally defined as having fidelity. The primary research areas in the Long-Term Path of Section II, address both "perceptual fidelity" and "training fidelity."

TRAINING EFFECTIVENESS

A simulator is characterized as being effective in the training of some task or maneuver to the extent that training using the simulator results in less training being required in the aircraft to attain or maintain performance criteria. Obviously, a simulator is then ineffective if training in it results in no change in or an increase in the amount of subsequently required aircraft training. Notice that this definition is silent concerning the amount of simulator training required to realize the training effectiveness; that is, it does not address the "training efficiency" of the simulator.

COST EFFECTIVENESS

Closely associated with training effectiveness is the concept of cost effectiveness, or the cost associated with attaining training effectiveness. Relative to some training alternative (usually the aircraft alone), a simulator is considered more cost effective if it allows achievement of the same training objective at a lower total cost.

In considering training-effectiveness and cost-effectiveness interrelationships, one should bear in mind that it is entirely conceivable that a simulator may exhibit training effectiveness but still be

cost ineffective compared to training using the aircraft alone. Simulator acquisition and/or operation cost may be so great as to offset the benefits realized from simulator training. On the other hand, a simulator with low acquisition/operation cost may be so lacking in training effectiveness that it also is not cost effective compared to other alternatives. This research plan is especially concerned with the relative cost effectiveness of various simulator design options and, in particular, with determination of the point or points at which the payback in training effectiveness fails to keep pace with the cost of increased fidelity.

BASIC ASSUMPTIONS AND CONCEPTS

All coherent programs of research, present effort included, must be guided by an explicit consensual set of assumptions and concepts. Those assumptions and concepts that apply to this program are discussed below. These have been derived from the literature review and form the basis for the Section II and the Section III research plans.

TRAINING RESOURCES AND REQUIREMENTS

A fundamental premise underlying this effort is that simulation will become an increasingly important tool in the Army aviation inventory. The growing constraints on in-flight training are seen as the primary driver for the increase. The litany of constraints includes increasing cost of aircraft operation, increasing cost of training ordnance, local limitations/prohibitions against terrain and night flight, and lack of adequate gunnery ranges. It is assumed that, in general, these constraints on training resources will grow more stringent over time.

At the same time, it is clear that training requirements are increasing. Aviation training must change its overall emphasis from individual aircrew training to combined arms training. New systems, such as the AHIP and AH-64, are being fielded with more and more complex subsystems which require more and more training. It must be assumed that, in general, the training requirements will continue to increase over time. Simulation is seen as the primary tool available to reconcile shrinking training resources with expanding training requirements.

ROLE OF FLIGHT SIMULATION

As was implied above, flight simulation, in concept, is to be considered merely as one of several alternative training media and not as an end unto itself. Flight simulation is only one of several methods at the disposal of the training developer for meeting the requirements of an integrated training system. However, in practice, the Army has in its most recent flight simulator acquisitions pursued a goal of

developing devices capable of training equally well the entire gamut of flight tasks. The immediate result of this course of action has been a low-density fielding of high-cost devices among a high-density trainee population. The cost of the devices limits their proliferation, and the size of the trainee population these few devices must service severely restricts the amount of simulator training time available to each trainee. There are reasons to suspect that the methods presently used to define training requirements (and consequently training systems) either are inadequate or are not applied with sufficient discipline, or both. The role of flight simulation is to fulfill specific training needs that are systematically determined as part of development of an integrated training system, but there is some question as to the validity of the present processes of identifying and filling training needs.

PURPOSES OF FLIGHT SIMULATION

In the broadest sense, flight simulation is an economy measure in flight training. The supposition has always been that relatively inexpensive simulator training can be used to replace some (preferably large) fraction of relatively expensive aircraft training in the attainment of some set level of flight proficiency. To date, the Army has used the principle of economy through simulator-for-aircraft substitution in current flight training operations as the primary purpose and justification for its flight simulation program.

In addition to flight-hour substitution, there are at least two other broad purposes for simulation. One is increased safety, not only during training but also during operational flight subsequent to simulator training on inherently dangerous tasks or maneuvers. The other purpose is increased operational readiness resulting from training conducted in the simulator that cannot be conducted effectively in the aircraft during peacetime. These two purposes are often ignored because their cost effectiveness are difficult to quantify. But the fact remains that increased safety and operational readiness are potentially significant benefits of current and future simulators, and the need remains to develop methods for quantifying the benefit derived from simulators so designed.

AREAS OF APPLICATION

In general, all Army aviation training requirements can be classified using two dichotomous dimensions: stage of training and level of training participation. Stage of training can be categorized into skill acquisition training and skill sustainment training. Level of training participation can be categorized into individual training and collective training. The individual versus collective training distinction is fairly straightforward; the skill acquisition versus skill sustainment training distinction can be alternately conceptualized as how-to-fly

versus how-to-fight. Skill acquisition training refers to training that is primarily institutional and concentrates on learning to operate the aircraft competently. Skill sustainment training refers to training that is accomplished primarily in the field and (although it does not neglect aircraft operation) concentrates on learning to employ the aircraft as a combat system. Although there is in practice some overlap of training among the cells, this 2 x 2 categorization is useful in examining the status of present flight simulation applications and the directions future applications should follow.

Present Army flight simulators have all been designed with the primary application in one area: initial individual training. Acquisition strategy has been to evaluate prototype simulators' effectiveness for initial training of individual aviators in the institutional setting and then to procure production simulators, still built to answer initial individual training requirements, for sustainment of individual skills in the field. Along with the short shrift individual skill sustainment training has been given by Army simulation, an even greater void exists in the area of collective sustainment training. Even though there is a consensus that collective sustainment training requirements are going largely unfilled, the Army has only recently begun efforts toward developing simulators for collective or team training.

CONSTRAINTS ON SIMULATOR RESEARCH

To develop a realistic research program dealing with simulator design, it is essential to consider the constraints that make it difficult to design and conduct such research. Although a number of major and minor constraints exist for any type research, there are four constraints that have a major impact on the design and conduct of research to define the effect of simulator design on training effectiveness.

LACK OF RESEARCH EQUIPMENT

There is presently a lack of research equipment that would enable researchers to measure transfer-of-training as simulator design parameters are systematically varied. This constraint is particularly detrimental for research aimed at quantifying the training benefits realized from different levels of fidelity. This constraint can be removed by conducting some of the essential research using present simulators with temporary modifications (via the Short-Term Path) and by developing a research capability specifically for this application (via the Long-Term Path). The issue of research-equipment requirements must be resolved prior to undertaking any comprehensive program of research.

LIMITED ACCESS TO TEST POPULATION

Research on the use of flight simulators for institutional training disrupts the training process and may adversely affect the students' chances of successfully completing the institutional program. Similarly, research on the use of flight simulators for continuation training in the field is certain to disrupt unit training activities and, consequently, unit operational readiness. It is not surprising that both institutional training managers and unit commanders are reluctant to support such research. Unfortunately, an acceptable alternative to using aviators as subjects has not been found.

PERFORMANCE MEASUREMENT

In principle, an output on nearly any control action and nearly any flight parameter of interest can be obtained from current flight simulators. Yet, a great deal remains to be learned about the set of parameters that constitute the most valid and reliable index of proficiency on a given flight task or maneuver. Obtaining objective measures of flight proficiency is an even greater problem in the aircraft because both an instrumented aircraft and an instrumented range are required to obtain accurate measures of aircraft attitude and position. Again, relatively little is known about the set of measures that constitute the most valid and reliable index of flight proficiency in the aircraft. Although valid research is possible using instructor pilots' judgments of proficiency, more efficient research would be possible with an automated performance measurement capability in both the simulator and the aircraft.

EFFECTIVENESS ASSESSMENT METHODOLOGIES

The literature contains well-defined methods and indices for measuring the extent to which training in a training device transfers to performance in the aircraft. However, these methods and indices apply only to the initial acquisition of flying skills. Far less has been accomplished in developing methodologies appropriate for assessing the utility of a training device for preventing the loss of flying skills already acquired or for reacquiring skills that have degraded as a result of lack of practice. Such methodologies are essential for assessing the utility of flight simulators for sustainment training and refresher training.

PROPOSED PROGRAM OF RESEARCH: AN OVERVIEW

The broad objective of the program of research is to compile data needed to specify, for individual flight tasks, the fidelity of each simulator design parameter and training feature that will yield the most cost-effective training. To accomplish this objective, research must be

conducted to quantify the relationship between fidelity and training effectiveness; and training-cost data must be collected or extrapolated to determine relative cost effectiveness of training alternatives. Specific research objectives that must be met by this program are as follows:

- Design and conduct research to obtain the data needed to quantify the relationship between training fidelity and training effectiveness.
- Design and conduct research to obtain the data needed to define the relationship between flight simulator life-cycle cost and training fidelity.
- Design and conduct research to define the type, cost, and training effectiveness of training methods and media that represent alternatives to simulator training.

A substantial amount of time and effort will be required to (a) complete the research needed to fully quantify the relationship between training fidelity and training effectiveness, and (b) apply the research findings in developing new flight simulators and other training devices. It is essential to recognize, however, that the aviator training problems that exist today cannot simply be ignored until this research has been completed and the results applied. One solution to this dilemma is to promulgate two complementary paths of research, as illustrated in Figure 1.

The Long-Term Path, which is to commence simultaneously with the Short-Term Path, is a program of primarily basic and exploratory research concentrating on training fidelity requirements and on training technique development. In this program, training and cost effectiveness of various training fidelity profiles will be evaluated, and emerging/future training hardware capabilities will be exploited. Thus, the program must remain flexible in order to remain responsive to advances in technology and also to changes in operational requirements.

The Short-Term Path is a program of research that is aimed at evaluating and optimizing the use of the family of flight simulators that the Army already has acquired or has contracted to purchase. For the most part, the design of this family of flight simulators is fixed or will have been fixed long before the research envisioned for the Long-Term Path can be completed. (Flight simulators in this family include: the UH1FS, the AH1FS, the CH47FS, the UH60FS, and the AH64FS.) Thus, the fundamental objectives of the Short-Term Path research are (a) to determine the best way to employ the family of flight simulators that have been or are soon to be fielded, and (b) to identify design modifications (hardware and/or software) that will improve the training effectiveness of fielded simulators without incurring considerable product improvement costs.

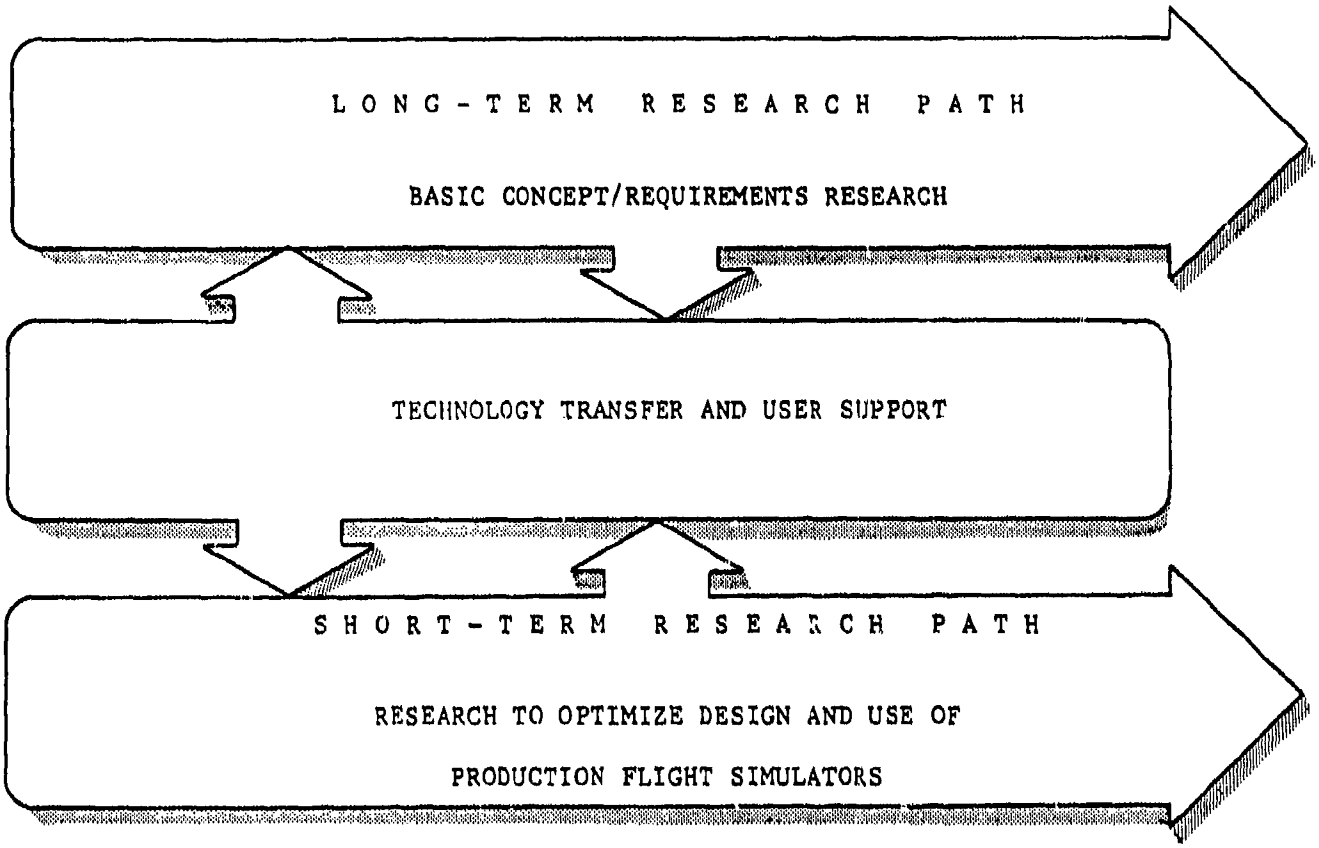

Figure 1. Long-Term and Short-Term Paths for Army flight simulator research.

The Short-Term Path research plan described in Section III focuses primarily on the use of flight simulators for unit training--that is, the training of aviators who have completed institutional training and have been assigned to an operational unit. The use of simulators in a unit-training context includes but is by no means limited to, skill sustainment training. As is discussed in Section III, it seems highly probable that flight simulators also will enable aviators to reacquire skills more efficiently (refresher training) and to acquire a higher level of skill (enrichment training) on some tasks than is possible through aircraft training alone.

Although the Short-Term Path research plan focuses primarily on the use of simulators for unit training, two other research projects are included that deal with the use of flight simulators for institutional training. The purpose of one project is to assess the extent to which contact flight training in a simulator equipped with an external visual system transfers to a UH-1H aircraft for initial entry flight students. This line of research has been given the acronym THIESIS (Training

Helicopter Initial Entry Students in Simulators). The fundamental question is whether a flight simulator can be used in lieu of the TH-55 aircraft to teach beginning flight students rudimentary flying skills. The purpose of the second project is to determine the extent to which Night Vision Goggle training can be accomplished in a flight simulator equipped with a visual system.

It is important that the limited focus on institutional training not be interpreted as an indication that there are no significant requirements for research to evaluate and optimize the use of flight simulators for institutional training. This is clearly not the case. The heavy emphasis on unit training applications of flight simulators is merely a matter of priorities. Many more simulators and many more aviators are involved in unit training than institutional training at a given point in time. Moreover, far less empirical data are available on the use of flight simulators for unit training than for institutional training. Considerable thought was given to proposing that a major research effort on institutional-training applications of flight simulators be conducted concurrently with the research on unit-training applications. This approach was rejected because of limited research resources and because of the high likelihood that the results of research conducted in the field-unit context will generalize to the institutional-training context.

Although not discussed as a part of this research plan, it is essential that a mechanism be established to ensure two-way communication between operational personnel and the personnel who are responsible for managing the Long-Term Path and the Short-Term Path research. The block in Figure 1, entitled "Technology Transfer and User Support," emphasizes this requirement. On the one hand, the research from both paths should yield findings that can immediately be applied to increasing the effectiveness of the Army's aviator training system. On the other hand, the research programs must remain responsive to the changes that affect training--system requirements and constraints such as: changes in the threat, changes in the Army's tactics and doctrine, changes in the training population, changes in resource limitations, the introduction of aircraft modifications, and the acquisition of new aircraft and weapon systems.

The next two sections of this report discuss the Long-Term Path and the Short-Term Path research in detail.

SECTION II

BASIC CONCEPT/REQUIREMENT RESEARCH (LONG-TERM PATH)

This section describes the basic concept/requirements research proposed for the Long-Term Path. Although every research topic discussed in this section addresses recognized problems associated with training Army helicopter aviators, many of the research topics are not unique to Army aviator training. A substantial proportion of the topics are presently under investigation by one or more branches of the U.S. military or by private industry. Furthermore, plans to initiate research on other germane topics have already been made by the U.S. Army (PM TRADE, 1982), by other branches of the U.S. military (AFHRL, 1983), and by industrial organizations.

So, the implementation of the proposed program will not necessarily require the establishment of new research agencies or the establishment of new work areas within existing research agencies. For the most part, the activities required to implement the proposed program consist of (a) redirection, change in emphasis, or change in scope of research that is presently underway or planned; and (b) establishment of a mechanism to ensure effective interagency coordination.

Because of the availability of research facilities and personnel, it seems certain that research on many topics of interest can be conducted at agencies such as the Ames Research Center, the ARI Field Unit at Fort Rucker, ARI Headquarters, the Army Human Engineering Laboratory, the Air Force Human Resources Laboratory (AFHRL), and the Naval Training Equipment Center (NTEC). However, when research is conducted at AFHRL or at NTEC, it is essential that Army representatives be involved in the research design to ensure that the results can be generalized to rotary-wing aircraft and to Army missions.

GENERAL OBJECTIVES

The general objectives of the long-term line of research are fully responsive to Secretary Scully's tasking of the Simulator Steering Group. They are as follows:

- to design and conduct research that will yield the data needed to quantify the relationship between fidelity (in selected flight simulator design parameters) and training transfer (for selected flying tasks),

- to design and conduct research that will yield the data needed to define the relationship between flight simulator production costs and required fidelity in the selected flight simulator design parameters, and
- to design and conduct research to define the type, cost, and effectiveness of alternate training methods and media[1] that could be used in lieu of flight simulators to train one or more of the selected flying tasks.

OVERVIEW

Figure 2 illustrates the main attributes of the long-term line of research. First, the figure lists the areas in which some form of research must be conducted in order to accomplish the general research objectives presented above. The primary research areas are the first ones listed: "Fidelity Requirements" and "Instructional Support Features." The remaining research areas are considered supportive in the sense that problems or uncertainties in each of these areas must be resolved in order to conduct effective research in the primary research areas. In this sense, the supportive research areas can be considered no less essential to the success of the long-term research program than the primary research areas.

Second, Figure 2 emphasizes that the long-term line of research must not only be responsive to current operational requirements, but must also be designed to recognize and accommodate (a) changes in operational requirements and (b) advances in training and training-device technology. It is essential that every attempt be made to design the research in such a manner that the findings and conclusions are not invalidated by changes in operational requirements or by technological innovations.

Finally, Figure 2 identifies the purposes served by the research findings. As was indicated in Figure 1, the results of the long-term line of research will have a direct impact on the other elements of the proposed R&D program. Specifically, germane research findings will be employed to improve the design and use of fielded components[2] of the

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[1]The term "training media" is used in its broadest sense throughout this plan. The term encompasses self-study books and manuals, classroom teaching aids and equipment, and equipment generally referred to as training devices. Where more specificity is required, the specific media will be named. This usage corresponds to that recommended in MIL-T-29053A(TD) (1979).

[2]This assumes that some of the results of the long-term line of research will be available soon enough to have an impact on the short-term line of research.

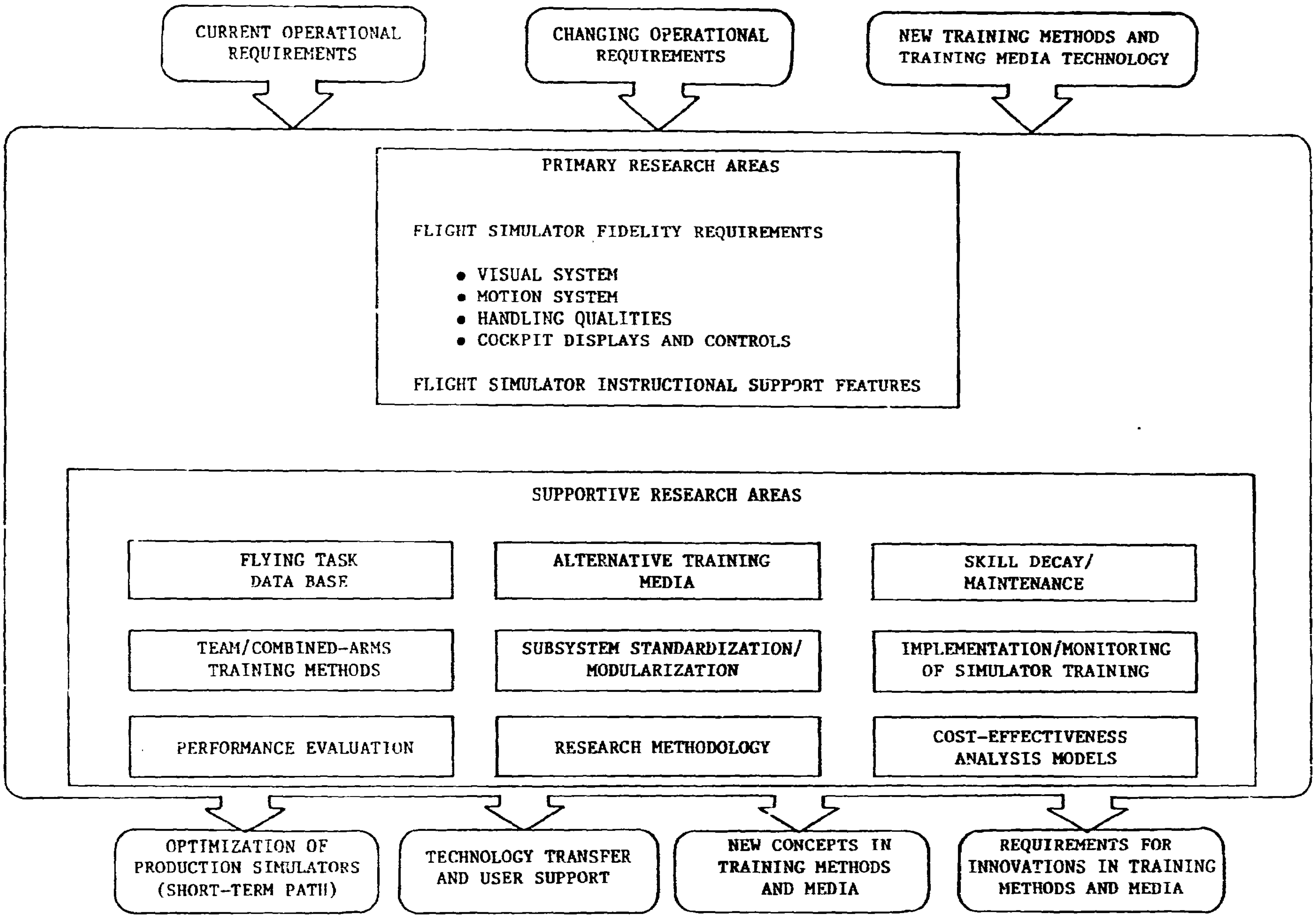

Figure 2. Critical research areas and outputs of long-term research.

flight-training system (Technology Transfer and User Support). Additionally, the long-term line of research should serve to (a) generate new concepts in training methods and training media, and (b) highlight areas in which there is an urgent need for innovation in training methods and training media technology.

Each of the research areas is discussed below. The primary research areas--Fidelity Requirements and Instructional Support Features--are discussed in considerably more detail than the supportive research areas because, for the most part, they are more complex and of more central importance. In every case, however, an attempt has been made to explain why research in the area is needed and to describe, at least in general terms, the type of research that is needed.

The main focus of the long-term line of research is clearly "simulator fidelity requirements." The objectives of research in this area are precisely the same as those stated earlier. In order to quantify the relationship between fidelity and training effectiveness, the effect of fidelity on training must be investigated for at least four components of a flight simulator: the visual system, the motion system, the handling qualities, and the simulator cockpit displays and controls. A discussion of the research requirements for each of these components is followed by a discussion of the research required in the area of training techniques.

The term "Instructional Support Features" (ISF) is used in Figure 2; throughout this report, ISF refers to simulator hardware and software capabilities that allow the instructor/operator to manipulate, supplement, and otherwise control the learning experiences of the student to maximize the rate and level of skill acquisition (Hughes, 1979). Research on ISFs has been selected as a primary research area because ISFs have the potential for having a major impact on both simulator cost and training effectiveness. Caro (1977b) has argued convincingly that instructional methods used in flight simulator training may have as much or more impact on training effectiveness as the training-equipment design. Empirical support for Caro's argument is found in a study of different levels of visual scene fidelity for a shiphandling/shipbridge simulator (Hammell, Gynther, Grasso, & Gaffney, 1981). In that study, instructional method differences were found to have several times as much impact on training effectiveness as any of the fidelity of simulation variables that were studied. Furthermore, there is considerable anecdotal evidence and some empirical evidence that many of the capabilities of contemporary Army flight simulators go unused because effective training techniques have not yet been developed (Charles, Willard, & Healey, 1976; Gray, Chun, Warner, & Eubanks, 1981).

The proposed long-term line of research is described under the six major subsection titles listed below:

- Fidelity Requirements for Visual System,
- Fidelity Requirements for Motion System,
- Fidelity Requirements for Simulator Displays and Controls,

- Fidelity Requirements for Simulator Handling Qualities,
- Requirements for Instructional Support Features, and
- Supportive Research areas.

If this program is approved in principle, it will be necessary for members of the Army Flight Simulator Steering Group to meet with representatives of selected Army agencies and with representatives of other branches of the service to establish priorities for the research, to decide which service/agency should assume primary responsibility for each research area, to estimate the resources (personnel, equipment, and funds) required, and to establish specific milestones.

FIDELITY REQUIREMENTS FOR VISUAL SYSTEM

The characteristics of a flight simulator's visual system have an enormous impact on the range of flying tasks that can be taught in the simulator and on the effectiveness with which they can be taught. The characteristics of a simulator's visual system also have an enormous impact on the simulator's procurement cost, operation costs, and maintenance costs. For more than two decades, there has been a continuing effort to produce visual systems with ever-increasing fidelity. Simulator designers and users alike have assumed that higher fidelity visual systems will result in more effective training. This assumption may have been more or less valid until recently. Currently, however, visual-system technology is advancing at such a rapid pace that manufacturers may be capable of producing more visual-system fidelity than the Army needs or can afford. As a consequence, it is considered essential that the Army initiate a long-term research effort aimed at quantifying the relationship between training effectiveness and the fidelity of the scene produced by the visual system.

KEY ASSUMPTIONS

Image Generation

The components of a flight simulation visual system can be classified into two broad categories: image generation components and display components. The focus and scope of the proposed research has been influenced by assumptions that must be made about future technological developments in both image generation and image display.

The image generators in current use are of two types: Camera-Modelboard (CMB) systems and Computer Image Generation (CIG) systems. Although CMB systems have been used with considerable success in training some types of flying tasks (AGARD, 1980; AGARD 1981), CMB image generators have a number of inherent shortcomings that limit their utility, especially for use in training military flight maneuvers that occur close to the ground. The various shortcomings of the CMB approach to image generation have been identified and discussed by Wekwerth

(1978), Breglia (1980), and Gullen, Cattell, and Overton (1980), among others. The shortcomings most commonly cited include:

- inadequate depth-of-field,
- inadequate image resolution and clarity,
- restricted roll and pitch,
- limited size of gaming area,
- high cost of modifying gantry, probe, and modelboard,
- unacceptable mechanical lags and overshoots,
- inadequate position resolution,
- difficulty in producing desired special effects, such as weapons effects and atmospheric attenuation,
- problems resulting from probe crash,
- inability to provide additional detail, beyond a certain point, as camera closes on the modelboard,
- unacceptable distortion of imagery in the periphery,
- difficulty in achieving a wide field-of-view while maintaining adequate brightness and resolution,
- poor reliability and maintainability,
- difficulty in generating synthetic effects, such as aim points, hit marks, and highways in the sky,
- large amount of space required to house modelboards, and
- extensive amount of energy required to power the large banks of lights and the climate control equipment.

Although contemporary CIG systems also have a number of shortcomings (for example, see Gullen et al., 1980), CIG technology is advancing at such a rapid pace that many of the shortcomings are almost certain to be overcome in the short- to mid-term time frame. Based on the information presently available, it seems reasonable to assume that the visual systems of future flight simulators will be built around a CIG system. Other image generation techniques, such as videodisc, film transparencies, or large-scale CMBs, may be used to supplement the computer-generated imagery when the CIG cannot produce imagery that is sufficient to train some types of tasks. It follows from these assumptions that research to quantify the relationship between training efficiency and visual-system fidelity must focus mainly on computer-generated imagery. This conclusion has had a major impact on the direction of this research plan.

A factor constraining research on required fidelity of computer-generated imagery is the availability of CIG systems with which to investigate a wide range of variations of the scene content and level of abstraction. A substantial capability to investigate the effect on

performance of computer-generated image fidelity is provided by (a) the Air Force's Advanced Simulator for Pilot Training (ASPT), located at the Air Force Human Resources Laboratory, Williams Air Force Base, Arizona; (b) the Navy's Visual Technology Research Simulator (VTRS), located at the Naval Training Equipment Center, Orlando, Florida; and (c) an Evans and Southerland (CT-5) CIG now being procured by the Ames Research Center for use on the Rotorcraft System Integration Simulator (RSIS). It would be premature to judge whether these CIG systems are capable of generating, or could be modified to generate, the variations in scene content and level of abstraction that is necessary to investigate fidelity requirements for the full range of helicopter flying tasks; several of the proposed research tasks discussed later will have to be completed before such a judgment can be made. In any event, the proposed research on visual-system fidelity requirements assumes that suitable devices or methods for producing suitable computer-generated imagery will be available when the time comes to initiate the research. If the CIG systems identified above lack the required capability, it is probable that new CIG devices now under development can be used to generate, perhaps in non-real time, imagery that will be suitable for research purposes (Csuri, Hackathorn, Parent, Carlson, & Howard, 1979; Deel & Rue, 1980; Dichter, Doris, & Conkling, 1980; Spooner, Breglia, & Patz, 1980; Schumaker, 1980).

Image Display

High quality computer-generated imagery yields no benefits if the visual display component of the visual system is incapable of presenting the image to the viewer without degrading it significantly. Currently, the visual display component is clearly a weak link in the visual system. Contemporary display technology is incapable of presenting sufficiently high resolution and brightness while maintaining an adequately large field-of-view. In addition, visual display technology is limited in its ability to simultaneously provide relatively wide field-of-view imagery to two or more crew members located several feet apart without parallax or position errors (AGARD, 1981; Suminski & Hulin, 1980). A substantial amount of work is underway in industry to improve visual display capability. Promising devices that are now under development or are being refined include:

- CRT projectors,
- laser projectors,
- liquid-crystal light valves,
- oil-film type light valves,
- titas light valves,
- high-resolution beam-penetration CRTs,
- full-color collographic displays,
- large size CRTs, and

- display optics (improved optical design and improved techniques for producing both large refractive and reflective plastic optics).

The plan for long-term research on visual systems was written with the assumption that, by the time the research is initiated, display devices will be available that have the capability to produce a sufficiently wide range of relevant design parameters including but not necessarily limited to the following:

- field-of-view (FOV),
- viewing region,
- resolution,
- brightness,
- distortion,
- contrast,
- color, and
- tonal range.

However, one cannot dismiss the possibility that technological innovations may make it unnecessary to investigate the relationship between performance and some of the design parameters. For instance, the development of a method for producing a low-cost, high-brightness display may make it unnecessary to investigate brightness as an independent variable.

Fidelity/Task Interactions

There is ample evidence that skill on some relatively simple flying tasks can be acquired effectively with a very simple and abstract display format (Williams & Flexman, 1949; Flexman, Matheny, & Brown, 1950; Flexman, Townsend, and Ornstein, 1954; Creelman, 1959; Hennessy, Lintern, & Collyer, 1981; among others). Effective training on other more complex flying tasks probably will require more complex display formats, although there are currently little empirical data either to support or to refute this claim. As a consequence, it has been assumed that a sufficiently comprehensive research program must provide data on the relationship between visual-system fidelity and training effectiveness for each of a representative set of training tasks. It is further assumed that visual-system research on a given task cannot necessarily be generalized from fixed-wing to rotary-wing aircraft. For instance, it cannot be assumed that a visual system that provides cost-effective training on low-level flight in a fixed-wing aircraft will provide cost-effective training on NOE flight in a rotary-wing aircraft.

Research to optimize the design of complex systems is often complicated by the sheer number of design parameters that must be investigated. Research to define the most cost-effective level for visual systems is no exception. All of the design parameters listed above are potential independent variables. In addition, all the scene elements that may influence the content and level of abstraction of a

computer-generated scene are potential independent variables. The problem is complicated even further by the assumption that the level of visual-system fidelity that yields the most cost-effective training is certain to vary as a function of the type of flying task being trained and the specific training technique used. Considering the number of parameters involved and the levels of each parameter that must be investigated, it is clear that addressing all levels of all parameters in a single, complete-factorial study is out of the question. It has been assumed that analytical studies can be used to pare down the independent variables to a manageable number before empirical research is commenced. This is not to suggest, however, that behavioral scientists are sufficiently knowledgeable about human perceptual processes to enable them to define visual-system design requirements through analytical considerations alone.

Cost Data

Visual-system designers and users cannot make judicious decisions about how much fidelity to buy without knowledge about the cost of the hardware, software, and data base needed to produce different levels of visual-system fidelity. At the present time, such cost data are extremely difficult to obtain. It may be possible to derive reasonably accurate estimates of the cost of individual elements of the display component of the visual system. However, it is much more difficult to estimate the cost of CIG systems as a function of the level of fidelity of the imagery they can produce. One reason for this difficulty is that vendors of CIG systems are understandably reluctant to release any cost data or technical information that may benefit their competitors. A second reason is that neither CIG vendors nor CIG users have conducted the research needed to identify the CIG elements that are the main cost drivers. The failure to have identified cost drivers is due, in large part, to the rapidly changing technology; a CIG feature that is an important cost driver in one prototype may be among the least important cost drivers in the next prototype. (See Suminski & Hulin [1980] for a more detailed discussion of the problems associated with developing an effective costing model for CIG systems.) The plan for long-term research on visual systems assumes that it will be possible to compile the cost data needed to develop a reasonably accurate costing model by the time such data are needed to evaluate the research findings.

RESEARCH OBJECTIVES

The objective of the research on visual-system design is to compile the data that visual-system designers and users must have to answer the following sequence of questions for each candidate training task.

- What level of visual-system fidelity yields the most effective training on a given task?

- For the task under investigation, are there alternative training methods and media, including training in the aircraft itself, that yield more effective training?
- Are the training benefits of the most effective training method/media available (simulator or alternative techniques) great enough to offset the cost?

Three types of data are needed to answer such questions. First, data are needed with which to quantify, for each candidate training task, the relationship between visual-system fidelity and training effectiveness. Second, data are needed with which to identify alternate training techniques (including training in the aircraft) and to assess their training effectiveness. Third, data are needed with which to assess (a) the cost of training the task in the flight simulator (for each level of visual-system fidelity investigated) and (b) the cost of training the task using each training technique determined to be a viable alternative to simulator training.

DESCRIPTION OF RESEARCH PLAN: VISUAL-SYSTEM FIDELITY REQUIREMENTS

A detailed description of the research plan designed to address visual-system fidelity requirements is presented in the following pages. It is important to note at the outset that the research plan was not formulated with any preconceived notions about the tasks that should be or should not be trained in the simulator. In particular, it has not been assumed that an essential goal is to field a "full combat-mission simulator" that can be used to train all or even a majority of the tasks that aviators must master in their quest for full operational readiness. Conversely, the research plan has been designed to cull out tasks that should not be trained in the simulator because (a) a more cost-effective training method/media is available, (b) training the task in a flight simulator would require an unacceptably large increase in the visual-system's complexity and cost, or (c) training the task in a flight simulator would require a visual-system capability that exceeds the existing and projected state-of-the-art.

Without question, the most important and most difficult aspect of visual-system design is the task of defining the least costly CIG scene content that will provide effective training on a given task. The importance stems from the fact that, in the final analysis, it is the scene content[3] that dictates the design requirements for both the CIG and the display elements of the visual system. The difficulty stems

[3]Scene content, as the term is used here, includes the full set of objects and features that may become visible during the performance of the flying task(s) under investigation. Only a portion of the objects/features that comprise the scene content may be visible on the display at a given time.

from the lack of objective techniques for bridging the gap between training task descriptions and CIG scene content specifications.

Behavioral scientists who are knowledgeable about flight simulator visual systems generally agree that far too little is known about human perceptual processes to enable one to logically derive the least costly CIG scene content that would provide effective training on even the simplest flight maneuvers (Hennessy, Sullivan, & Cooles, 1980; Richards & Dismukes, 1982; Semple, Hennessy, Sanders, Cross, & McCauley, 1981a; Thorpe, 1978). Although designers of contemporary visual systems have made what appear to be reasonable guesses about CIG scene content, the fact remains that the design decisions have been based more on intuition than known facts and principles about human perception in flight. Hence, it seems clear that it is not now possible to define CIG scene content through analytical procedures alone.

A purely empirical approach to defining CIG scene content is no more feasible than a purely analytical approach. Scene content and the level of abstraction of a CIG display can be varied in such a large number of different ways that it would be impossible to investigate the training effectiveness of every display format, even with the efficient multifactor designs currently available (see Simon [1973, 1977, 1981]; and Simon & Roscoe [1981] for discussions of the use of efficient multifactor designs in simulator research).

Although CIG scene content is a critically important issue, research to define the fidelity requirements for visual systems must also address the host of visual-system design parameters that influence image quality (resolution, contrast, distortion, etc.) and the question of field-of-view. However, research to define the most cost-effective scene quality and field-of-view cannot be designed until one has a clear notion of what is to be displayed and the tasks that are to be trained. Once the tasks to be trained and display content are known, it is possible that existing psychophysical data, such as that compiled by Kraft, Anderson, and Elworth (1980), will be sufficient to make judicial decisions about display quality and field-of-view.

The above considerations led to the formulation of a research plan that employs both analytical studies and empirical research. The plan is depicted schematically by the task-flow diagram shown in Figure 3. Many of the tasks shown in Figure 3 overlap, wholly or in part, with one or more of the nine supportive research areas listed in Figure 2. The ellipses in Figure 3 serve to identify the end products generated by the composite research effort.

Compile List of Training Tasks/Conditions

It is essential that this research effort commence with a comprehensive listing of the tasks that Army aviators must learn and the full set of conditions in which aviators must be able to perform each task.

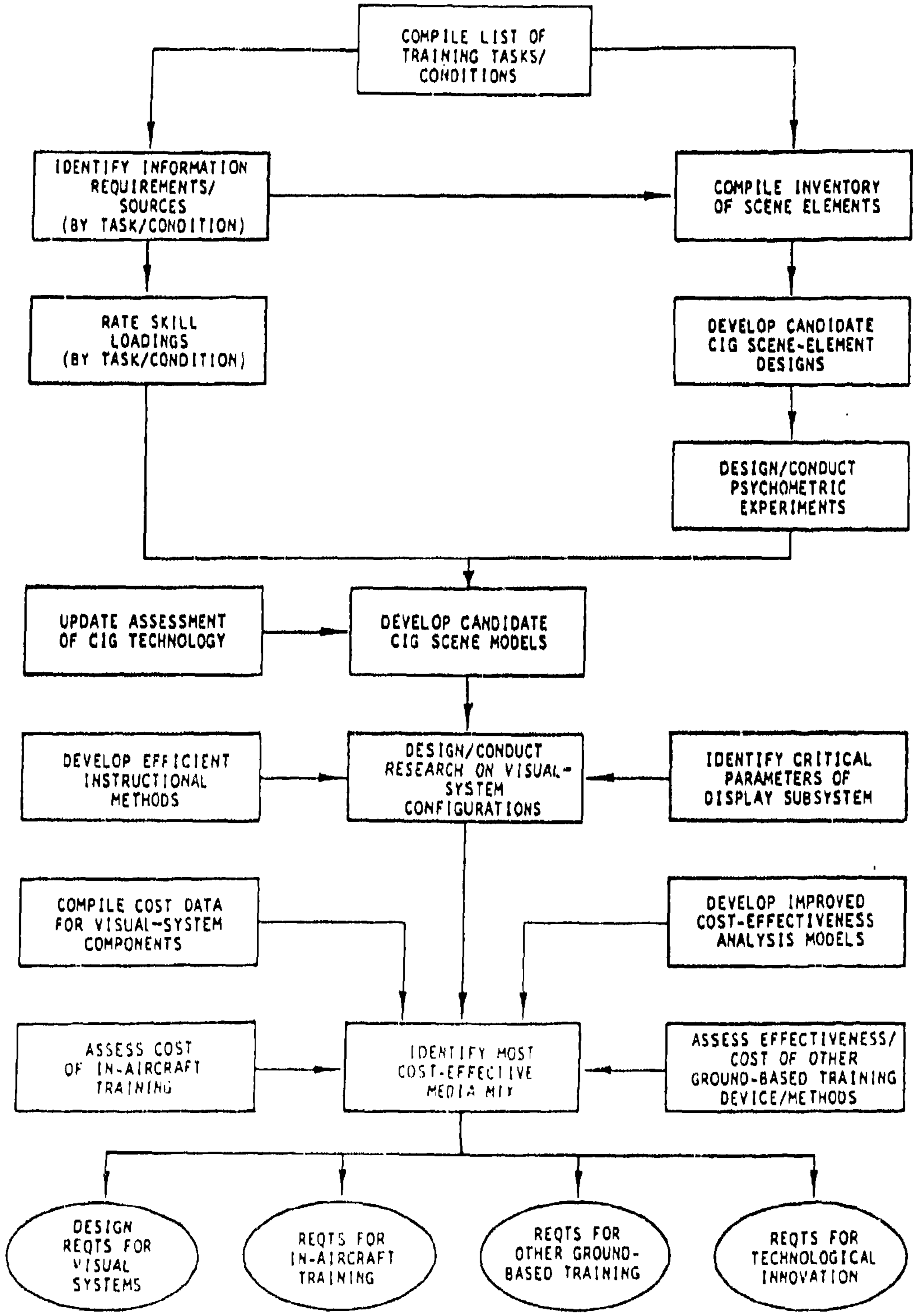

Figure 3. Task-flow diagram for long-term research on CIG-based visual systems.

The task list must include the full complement of tasks for every rotary-wing aircraft in the Army's inventory. At the beginning of the effort, the list of tasks/conditions will be used in performing an information requirements analysis and will serve as a reference in developing candidate scene-element designs. Subsequently, the list of tasks/conditions will be used to formulate a specific plan to assess the relative utility of candidate visual-system configurations.

A tentative task list has been compiled and is presented in Appendix A. Appendix A lists 124 different tasks and shows the aircraft types (TH-55, UH-1, OH-58, CH-47, UH-60, AH-1, AH-64, and AHIP Scout) in which each task is performed. Appendix B shows a tentative listing for one aircraft type--the AHIP Scout--of the full set of conditions under which fully trained aviators must be able to perform each task. Appendix B shows that a CIG system for a full-mission simulator for the AHIP Scout aircraft must be capable of generating (a) day scenes with various types and levels of atmospheric attenuation (haze, fog, smoke, dust, rain, and snow), (b) night scenes that vary in illumination from full-moon to starlight conditions and various types/levels of atmospheric attenuation, and (c) the imagery produced by various types of sensors (day TV, low-light-level TV, and infrared) and optical magnification devices. It is obvious that the CIG systems that are capable of generating only clear, daytime scenes are able to provide training on only a small fraction of the visibility conditions that Army aviators can be expected to encounter in combat.

Identify Visual Information Requirements/Sources

A fundamental assumption underlying this effort is that there is no better way to formulate hypotheses about the CIG scene content that is most suitable for training a given flying task than to examine the visual information that experienced aviators[4] employ when performing that task in the aircraft. Accordingly, the purpose of the task described here is to (a) identify the visual information that experienced aviators employ to perform each task under each of the relevant visibility conditions, and (b) identify the one or more sources of each type of information employed.

As is discussed in more detail later (see page 95), it is proposed that data on visual information requirements/sources be compiled as a part of a major effort to develop a flying-task data base. It is envisioned that these data would be more comprehensive and detailed than the training requirements data base that is routinely produced in

[4]It is not assumed that aviator trainees employ precisely the same visual information as experienced aviators. However, it is assumed that, for any flying task, the visual information employed by trainees is a subset of the visual information that experts employ.

conjunction with new Army weapons systems. The following discussion addresses the methods and procedures for compiling the data on visual information requirements.

There are at least three methods for collecting data on visual information requirements/sources: subjective assessments by experienced aviators, eye-movement recordings, and experiments in which visual information is systematically varied as an independent variable. Because each of these methods has its own advantages and shortcomings, it has been judged that all three are required to obtain the data that are needed.

Aviator Assessments

The view is common among simulation researchers that the subjective assessments of aviators are not a reliable guide to the visual information required to perform a specific flying task. Other researchers, such as Fender (1982), argue that a wealth of valuable information resides with aviators and that the reported unreliability of aviators' judgments reflects inadequate methods for tapping this data source, inadequate methods for analyzing the data, or true differences in aviators' perceptual strategies. The authors of this research plan share Fender's views about the potential value of experienced aviators' subjective assessments and believe that effective procedures can be developed to obtain valid and useful data from them.

Much of the difficulty in obtaining valid information from aviators stems from the aviators' lack of understanding of the complex questions they are asked, the small amount of time they are typically given to reflect on the questions, and the lack of the vocabulary and the concepts needed to express their views concisely. To counter these problems, it is proposed that a team of at least six experienced helicopter aviators be assigned to this project full time for a period of about six months and that the aviators be given training on at least the following topics before they are asked to provide information about information requirements and sources:

- research objectives and plans,
- anatomy and functioning of the human eye,
- known principles of human perception in flight,
- known or probable variability among aviators in the types/sources of visual information employed, and
- methods/principles of rating/scaling.

The first thing the aviators will be required to do after their initial training is (a) to identify, for each task/condition, the subtasks for which performance is dependent, wholly or in part, on extra-cockpit visual information, and (b) to define performance standards for each of the relevant subtasks. A group decision-making

technique, such as the Consensual Decision-Making Technique (Delbecq, Van de Van, & Rustafson, 1975), will be used to accomplish this task. The "subtask" will be the unit of further analyses. The performance standards serve as an index of the precision with which vision-based decisions must be made.

The next task that must be performed by the team of aviators is to identify the type, source, and relative importance of visual information used in accomplishing each subtask for which some amount of extra-cockpit information is necessary. In order to accomplish the objectives of this task, it will be necessary to develop and validate better research methods than the ones that are presently available; the new research methods must be more systematic and must be specifically tailored to provide the type of information needed to formulate hypotheses about CIG scene content. The development and validation of suitable methods will require far more time than was available for developing this research plan. However, some thought has been given to the shortcomings of existing methods and to the attributes of a more suitable methodology.

Heretofore, visual information requirements typically have been defined in terms of the critical flight parameters that must be judged and in terms of the classical visual cues to depth and locomotion that provide information about the momentary value, or change in value, of the relevant flight parameters. (For examples of visual cue requirement analyses or research, see Coward & Rupp, 1982; Eisele, Williges, & Roscoe, 1976; Gibson, 1966, 1979; Gullen et al., 1980; Harker & Jones, 1980; Ozkaptan, 1975; Roscoe, 1977; Rue, Cyrus, Garnett, Nachbar, Seery, & Starr, 1980; and Stark, 1977.) While visual cue requirements studies are not without value, the results lack the specificity needed to make confident and specific judgments about the least costly CIG scene content for each of a number of flying tasks. Furthermore, conclusions drawn from the analysis of visual cue requirements are sometimes erroneous or misleading. For instance, Stevens (1980) has pointed out the error in the intuitive conclusion drawn by some researchers (Gibson, 1950; Purdy, 1960) that texture density is a crucial depth cue. Stevens explains that since texture density is a joint function of viewing distance and the slant of the viewed surface relative to the viewer, one cannot separate the relative contributions to the texture density gradient of foreshortening and distance. This ambiguity has been demonstrated empirically by Newman (1972).

Described below are some attributes that should be considered when developing a methodology for obtaining useful information from the group of experienced aviators concerning the type, source, and relative importance of visual information. Most of these attributes are aimed at providing structure and specificity to the difficult job of introspecting about how complex flying tasks are performed.

Small unit of analysis. One of the reasons that it is difficult to formulate accurate statements about extra-cockpit visual requirements

is that the requirements vary greatly from one condition to another. This is why it is so important to use a small activity, such as a subtask, as the unit of analysis. In this sense, it would be ideal to define a subtask as a segment of a flying task or maneuver during which visual information requirements (type/source/importance) remain constant.

Conceptual structure. There is a need for some type of conceptual structure that will aid aviators in considering the visual information requirements/sources for each subtask/condition. For instance, Stevens (1982) has suggested that (a) shape, orientation, and scale be regarded as the three types of 3-D information that are necessary for flying relative to the terrain and (b) all discussion about visual information requirements/sources be cast in terms of these three types of information, without any attempt to determine what "depth cues" are employed. In short, Stevens is suggesting that the rather simple notion of "depth cue" be abandoned in favor of three types of surface information. He believes that shape, orientation, and scale are terms that are understood by aviators and that the full range of visual information types and sources would be revealed by considering in a sequential manner the features in the real-world scene that are attended to in assessing one of the three parameters. Although Stevens' structure may not ultimately prove to be the best one available, it exemplifies the type of structure needed to ensure that the aviators' considerations are systematic and complete.

Aids to recall. Even when focusing on performing a specific subtask in a specific visual and topographic context, it may be difficult for aviators to recall enough about their past experiences to describe accurately the visual information requirements. Photographs, films, or video recordings of the visual scene during the performance of the subtask in question almost certainly would prove to be valuable aids to recall. In some instances, it may be cost effective to require the members of the pilot team to perform a subtask in flight, record their observations about visual information requirements at that time, and subsequently discuss their observations in a group setting.

Appropriate parameters/metrics. It is important that visual information requirements be expressed in terms of parameters and metrics that reflect the types of judgments that aviators must make in performing a task. Defining visual information requirements for NOE flight in terms of altitude, altitude rate, forward velocity, etc. seems sterile and misleading after hearing an experienced pilot describe NOE flight in terms of skid clearance, main rotor clearance, tail rotor clearance, masking, unmasking, closing velocity, etc. For example, when NOE flight is described in such terms, it is apparent that an aviator's visual information requirement is not altitude in feet ACL; rather, he needs to know whether the clearance between the lowest point on his aircraft and the tallest feature in his projected path is sufficient to avoid a collision. Similarly, when operating in a confined area, the aviator's visual information requirements cannot be defined meaningfully

in terms of aircraft flight parameters and standard metrics; his actual requirement is for the visual information he can use to judge the present and projected distance between his aircraft's main/tail rotor and obstacles in the immediate environment.

Judgment precision. An important aspect of visual information requirements is the precision requirements for judgments that must be based solely on extra-cockpit information. Without such information it is easy to require more accurate information from a CIG display than can be gleaned from the actual extra-cockpit scene. A cursory examination of the visual requirements for performing a standard autorotation may suggest that aviators must be capable of extremely accurate judgments of altitude throughout the maneuver. However, a careful examination of the prescribed method for performing a standard autorotation indicates that the only critical altitude judgments that must be based on the extra-cockpit scene alone are (a) the judgment of when altitude has decreased to between 75 and 100 feet (introduce cyclic control to decrease speed) and (b) the judgment of when altitude has decreased to between 10 and 15 feet (apply sufficient collective to minimize rate of descent and ground speed). Hence, there is no need for great precision in judging altitude from extra-cockpit cues throughout the performance of a standard autorotation.

Objective Research on Visual Information Requirements

Aviators' subjective assessments can be used to obtain visual information requirements data on a great many different tasks and conditions in a relatively short period of time and at relatively low cost. However, pilot judgments cannot be expected to yield data that are sufficiently comprehensive and detailed. For instance, it is unlikely that aviators will be able to introspect accurately about (a) the information they obtain through peripheral vision, (b) the length of time their eyes must remain fixated on relevant objects or areas in the visual scene, or (c) conditions in which the information that can be gleaned from the extra-cockpit scene is inadequate and must be supplemented by information from cockpit instruments. It is for this reason that the aviator assessments must be supplemented by objective research.

A substantial amount of time and study will be needed to make final decisions about the objective research that must be performed to supplement and validate aviators' judgments about visual information requirements. The four lines of research described below represent a current "best guess" about the type of research that may prove fruitful. All four lines of research are designed to yield data on performance in the aircraft. This reflects the general belief that investigating in-aircraft performance minimizes the chances of drawing invalid conclusions about visual information requirements. This is not to say, however, that research on some questions about visual information requirements might better be conducted in a laboratory setting.

Investigation of eye movements/fixations. The premise underlying the recording of aviators' eye movements is that data on aviators' scan patterns and fixation points can be used to draw valid inferences about the visual information requirements that can be fulfilled with foveal vision. A brief review of the literature on eye-movement recording of aviators precedes a description of the eye-movement research that is proposed.

In a comprehensive review of eye-movement recording methods, Young and Sheena (1975) report that attempts to record eye movements date back to the early 1920s. The earliest attempts to record aviators' eye movements used filming techniques to record eye fixations on cockpit instruments during both instrument and visual flight conditions (Fitts, Jones, & Milton, 1950; Jones, Milton, & Fitts, 1950; Milton, Jones, & Fitts, 1949, 1950; Milton, McIntosh, & Cole, 1951, 1952; McGhee, 1943; Milton & Wolfe, 1952).

The recording of extra-cockpit eye fixations had to await the development of more sophisticated equipment. The corneal reflection technique, pioneered by Mackworth and Thomas (1963), has been used to develop eye-movement recording devices that generate films or video recordings that show the scene being viewed and the point of instantaneous eye fixation in the scene.

Such devices have been used successfully to record rotary-wing aviators' intra- and extra-cockpit eye fixations during flight. Barnes (1970, 1972) recorded rotary-wing aviators' eye fixations during a 20-minute flight that involved 11 different maneuvers: takeoff, hover (in-ground-effect), vertical climb, cruise, standard rate turn, non-vertical climb, 180° turn, steep approach, hover (out-of-ground effect), vertical descent, and landing. All maneuvers except takeoff, hover (in- and out-of-ground-effect), and landing were performed with instruments only. A Westgate Model EMC-2 Eye-Movement camera was used to perform this research.

More recently, a NAC I Mark Recorder and a Photo-Sconic high speed motion picture camera have been used successfully by US Army Aeromedical Research Laboratory personnel to study helicopter workload (Simmons, Kimball, & Diaz, 1976), helicopter copilot workload (Cote, Krueger, & Simmons, 1982), scanning techniques of Coast Guard helicopter lookouts (Blackwell, Simmons, & Watson, 1982), and sources of visual flight information (Harker & Jones, 1980).

Although the above referenced research clearly confirms the feasibility and utility of eye-movement recording as a technique for defining aviators' visual information requirements, the composite of research data on eye movements of helicopter crewmen cover only a limited number of flying tasks and conditions. In short, the eye-movement data presently available have little value for use in defining CIG scene content for an adequate range of flight tasks and conditions. The equipment and procedures developed previously represent the main benefit to be derived from previous research.

The collection of eye-movement data for every flying task and condition listed in Appendices A and B, respectively, is neither feasible nor necessary. Rather, it is envisioned that eye-movement data would be collected on a small sample of flying tasks/conditions for one of three purposes. The first purpose is to provide a means for validating aviators' subjective assessments of visual information requirements. Once members of the team of aviators have completed their assessment of the types and sources of information required to perform several tasks, eye-movement recordings made during the performance of those tasks would provide information with which to evaluate the validity of the aviators' subjective assessments. Gross inconsistencies between eye-movement data and pilot assessments would signal a need to reexamine (a) the procedures used to tap aviators' opinions about visual information requirements, (b) the assumption that pilot opinion is a valid and reliable source of data on visual information requirements, and (c) the assumption that eye movements and fixations constitute a valid and reliable source of data on visual information requirements.

The second purpose to be served by eye-movement recordings is to obtain information on (a) tasks/conditions that aviators have experienced so infrequently that they have no strong opinions about visual information requirements/sources, and (b) tasks/conditions that are inherently difficult to evaluate through introspection. Within this context, examples of tasks/conditions that are likely to qualify for eye-movement study are operations over snow, operations in heavy smoke, operations in weather conditions that degrade visibility (fog, snow, low cloud ceiling), daytime NOE navigation in a variety of topography, and nighttime NOE flight and navigation. Existing eye-movement recording systems have been developed for use during conditions of relatively high illumination. Hence, in order to investigate the tasks listed above, it will be necessary to design devices that provide the capability to record eye movements during darkness and other conditions of reduced visibility.

The third use of eye-movement recordings is to provide more quantitative data than can be obtained from the subjective assessments of aviators. A need may arise for such data as fixation frequency and duration for different classes of features, time spent searching the extra-cockpit scene, the frequency with which aviators fixate on objects in different segments of the field-of-view, and link values that depict aviators' search patterns. Such data can be obtained only from the study of eye-movement recordings.

Investigation of the role of peripheral vision. Helicopter aviators' use of peripheral vision has important implications for both CIG design and the design of the display component of the visual system. The aviator assessment data and the eye-movement data, together, should provide a relatively clear notion of the visual information requirements that are fulfilled with foveal vision. However, these methods cannot be expected to provide data that are useful in drawing inferences about the information requirements fulfilled through peripheral vision.

Data on aviators' use of peripheral vision during flight would be of value in specifying the minimum field-of-view for flight simulators and, perhaps, in specifying the characteristics of the scene to be viewed peripherally. Such data would be of particular value in clarifying the role of peripheral vision during darkness and other conditions of reduced visibility.

It seems probable that useful insights about the function and importance of peripheral vision can be obtained by examining aviators' performance on selected flying tasks when different areas of the aviator's field-of-view have been occluded. One method developed to occlude an aviator's field-of-view is to place on the inside of the aircraft canopy an orange film that is transparent when viewed by the naked eye, but opaque when viewed through a blue visor (Yeend & Carico, 1978; Yeend, Watkins, Carico, & Palmer, 1978). This technique enables the safety pilot the full field-of-view while occluding portions of the subject's field-of-view. This technique is not ideal for investigating the importance of peripheral vision because there is no way to determine the information within the reduced field-of-view that is being processed peripherally. The field-of-view would have to be very small indeed to eliminate all indications of optic flow. In addition, it would be difficult to eliminate variations in visual information resulting from aviators' head movements.

What appears to be a better technique is to develop contact lenses that are opaque in the desired areas. With this technique, the portion of the retina that is occluded would remain constant regardless of the aviator's head and eye movements. It is technically feasible and would not be prohibitively costly to develop sets of contact lenses to occlude central vision and to occlude different amounts and locations of peripheral vision.

Investigation of the impact of image quality. In the past, there has been a continuing effort to improve the image quality of simulator visual systems--despite the fact that there is no body of data with which to quantify the relationship between image quality and training effectiveness. The tendency has been to establish requirements for image quality by examining the one or two training tasks that require the highest quality image. For example, arguments for the need for a very high resolution visual system have been based on the resolution needed to train such tasks as target detection and identification. In addition, the quest for increased image quality undoubtedly has been influenced by the generalized desire for displays that are more realistic and more esthetically pleasing.

Controlled laboratory studies will be required to collect the type of data needed to establish the most cost-effective image quality for the various flying tasks that are to be trained in the simulator. However, it is possible to gain useful insights about image quality requirements through studies in the aircraft. A methodology for such studies has been suggested by a Working Group sponsored by the Flight

Mechanics Panel of AGARD (AGARD, 1981, p. 66). The idea set forth by the Working Group is that information about the minimum image quality can be obtained by measuring the effect on flying performance of special eye glasses that degrade the real-world visual scene in various ways. It would be a relatively simple matter to produce sets of eye glasses that could be used to systematically vary effective brightness and color.

It is proposed that such a study be designed and conducted. Ideally, the study would investigate the effect of image quality on both the performance of skilled aviators and the rate of skill acquisition of aviator trainees. Moreover, the study should investigate the effect of image quality on a representative set of flying tasks that cover the full range of complexity and visual information usage.

Investigation of the role of stereopsis. Measures of stereo acuity recorded in the literature varies from two seconds of arc (Berry, 1948) to 24 seconds of arc (Graham, Riggs, Mueller, & Solomon, 1949). Using a stereo acuity value of 24 seconds, Stevens (1982) computed that the eye is sensitive to retinal disparity out to roughly 1800 feet. Most researchers have concluded that stereopsis does not contribute significantly to low-level flight in high-speed, fixed-wing aircraft because of the small amount of time objects remain in the stereoscopic zone (two seconds, assuming a speed of 500 knots, an altitude of 100 feet, and a stereo acuity of 12 seconds of arc).

However, this rationale cannot be used to dismiss stereopsis as an important cue for helicopter operations. Most of the helicopter maneuvers that are difficult to master occur at low speeds and at low altitudes. Nap-of-the-earth flight represents the extreme case; Ozkaptan (1975) reports that the aviator's maximum viewing range during NOE flight seldom exceeds 3000 feet. Sinacori estimates that the "immediate radius of concern" to an NOE aviator extends only to about 550 feet at the highest expected NOE speed of 100 kts (Sinacori, 1983, p. 66). In many instances, the objects in the visual scene that are of primary importance to the pilot are located within 100 feet of the aviator's eye. Hence, there are reasons to believe that proficiency for many flying tasks may be dependent on stereopsis. If performance on some tasks in the aircraft is importantly influenced by stereopsis, it is conceivable that training such tasks in a simulator without a stereoscopic display may result in negligible or, conceivably, negative transfer-of-training to the aircraft.[5] Cost considerations would probably prevent the development and use of stereoscopic CIG displays.

[5]Based upon the composite information presently available, it seems improbable that a stereoscopic display is essential for simulator training of any helicopter flying task. However, the data on this issue are by no means conclusive, and there are some who believe that resources should be expended to develop stereoscopic displays for helicopter simulators.

So, the only option would be to make no attempt to train, in a flight simulator, tasks for which performance is heavily dependent upon stereopsis.

The impact of stereopsis on flying proficiency could be assessed effectively and inexpensively by comparing trained aviators' performance on selected flying tasks under binocular and monocular viewing conditions. Although more costly and difficult, other studies could be conducted to assess the impact of stereopsis on rate of skill acquisition and transfer-of-training. Such studies would require that two groups of student aviators be trained, one under monocular and the other under binocular viewing conditions. If it is found that skill is acquired more slowly by the group initially trained under monocular viewing conditions, this group could be switched to binocular viewing conditions and data compiled on the amount of additional training required to achieve the level of proficiency exhibited by the group trained throughout under binocular viewing conditions. The data from such experiments would serve to identify flying tasks for which stereopsis is important (if any) and, thereby, flying tasks that may not be amenable to training in a flight simulator that is not equipped with a stereoscopic display.

Rate Skill Loadings by Task/Condition

It is convenient to think of each flying task as having three skill components: a perceptual component, a cognitive component, and a motor (aircraft handling) component. Knowledge of the relative difficulty of these three components is essential for the design of effective CIG display formats and effective instructional strategies. In rating what is referred to in Figure 3 as "skill loadings," it is not sufficient to consider only the inherent difficulty of the three task components. In addition, the ratings must take into account the skills that the student aviators possess at the time they commence receiving instruction on the task in question. This means that the relative difficulty of the three skill components for a given task will vary as a function of the sequence in which flying tasks are taught.

For instance, consider the relative skill loadings for the task "hovering in ground-effect (IGE)" and the task "hovering out-of-ground-effect (OGE)." At the time a student first receives instruction on IGE hover, he possesses all or most of the perceptual skills needed to detect vertical and translational deviations from the desired hover position. However, a substantial amount of training is required for him to acquire the aircraft handling skills required to null the deviations. After the student has mastered IGE hover, he is given training on OGE hover. At the time the student commences his training on OGE hover, he possesses the cognitive skills and the aircraft handling skills (motor skills) he needs to perform this task but lacks the perceptual skills he needs to detect, from a higher altitude, vertical and translational deviations from the desired hover position.

With such knowledge about relative skill loading on various flying tasks, it is easy to conceive of CIG display formats and instructional strategies that may facilitate the learning of the difficult perceptual components. For instance, the rate of skill acquisition might be increased by bypassing the aircraft equations of motion and providing the student with a simple positional control with which to null a simple forcing function that causes the aircraft to drift from the desired hover position. Under this condition, the student could focus all his attention on the perceptual component of the task.

The failure to consider the relative difficulty of skill components in the manner described above can lead to erroneous conclusions about how best to train students to perform a given task. For instance, some simulator designers have examined the skills required to perform NOE flight and have concluded that this task represents the ultimate in perceptual and aircraft handling difficulty. Although NOE flight does indeed require a high level of perceptual and aircraft handling skill, aviators possess a high level of such skills at the time they begin their training on NOE flight. Experienced aviators claim that navigation, a cognitive skill, is the most difficult component of NOE operations. If this is true, increased instruction on NOE navigation and decreased instruction on NOE flying (in a simulator or in an aircraft) may be called for.

The ratings of skill loadings should be performed by a team composed of highly experienced aviators and behavioral scientists who are knowledgeable about helicopter flying operations, task/skill requirement analysis, and training. The team of aviators selected to define visual information requirements and sources should be highly qualified to make skill component ratings once they have completed their deliberations on visual information requirements and sources. However, to ensure reliable ratings, the team should be supplemented by another six to 10 aviators.

Special Comment

The ultimate aim of the four tasks that follow is to formulate hypotheses about CIG display formats[6] that may prove effective in training helicopter aviators. The comments presented below discuss some of the problems associated with specifying suitable display formats and ways to deal with these problems.

The literature contains little information of value in specifying the elements that should be present in a CIG scene for helicopter aviator training or the manner in which these elements should be

[6]The term "display format," as used here, encompasses both the type of features that appear in the scene and the level of abstraction of the feature's portrayal.

designed. The established principles of human perception are too general to provide a basis for the analytical derivation of specifications for scene content and element design; and, the small amount of research in which scene content and element design have been investigated as an independent variable has dealt with fixed-wing aircraft flying tasks, such as carrier landings (Westra, 1982; Westra, Simon, Collyer, & Chambers, 1982) and high-speed terrain flight (Buckland, 1980). The extent to which the findings of such studies can be generalized to helicopter operations is questionable, at best. The net result is that the design of display formats for use in training helicopter aviators must start, very nearly, at square one.

Researchers who have considered CIG scene content agree that there are no generally accepted procedures for defining optimal scene content or the optimal design of scene elements (Hennessy et al, 1980; Semple et al., 1981a; Thorpe, 1978, among others). The procedures suggested below are heavily dependent upon intuition and innovation to develop candidate display format. Although the enormous number of combinations of display elements and element designs necessitate the use of intuition and analytical study, no firm conclusions will be drawn until the candidate display formats have been submitted to empirical tests.

Before any meaningful effort can be expended in developing candidate scene designs and candidate scene-element designs, it will be necessary to formulate specific assumptions about the capabilities of the visual system to be used in evaluating the scene-element designs. Specifically, it will be necessary to formulate assumptions about (a) the design characteristics of the CIG system, (b) the content and format of the CIG data base, (c) the methods and procedures by which the data base is compiled, and (d) the characteristics of the display subsystem. Together, these four factors dictate the capabilities and constraints for scene-elment design.

Although the display subsystem is no less important than the other portions of the visual system, display technology is changing less rapidly and has less of an impact on visual-system costs than the technology bearing on CIG design and data-base generation methods. So, it is anticipated that the greatest uncertainty and risk will be associated with deciding upon the CIG and data-base capabilities that are to be assumed.

The most modern CIG systems in the government's inventory are by no means obsolete, but technology now under development promises significant advances in CIG technology within the next two to five years. It is altogether possible that by the time the research on scene-content and scene-element designs is initiated, significant technological breakthroughs will be imminent but not yet incorporated into an operational device. Truly major technological advances in CIG or data-base technology may justify delaying the research until a state-of-the-art CIG can be procured. Or, it may be possible to develop techniques for producing, in non-real time, imagery that could be used

to evaluate scene-content and scene-element designs that the new technology will be capable of generating.

The primary goal of most of the recent advances in CIG technology has been to increase the number of edges or polygons that are available for use in creating scene elements. Increases in edge capacity have been achieved through improved system architecture and through improved microelectronic components that provide for greater computational speed and better on-line and off-line memory utilization (see, for example, Dichter, Doris, and Conkling, 1980; Schumaker, 1980; Spooner, Breglia, and Patz, 1980). In 1979, Cohen (1979) predicted that CIG systems capable of producing as many as 100,000 edges in real-time would be available by the mid 80's. Cohen's prediction of large increases in edge capacity has not yet been realized; contemporary CIG systems are capable of producing only about 8,000 edges in real-time. Gullen and his colleagues (Gullen et al., 1980) share the view that all contemporary CIG systems employ the same general design approach and that this design approach has intrinsic limits to growth. They believe that refinements could increase the edge capacity by a factor of two or three, but that altogether new approaches will be required to achieve larger increases in CIG capacity.

Since scene-element design is so heavily dependent upon CIG and data-base characteristics, an attempt has been made to identify technological innovations that may have a major influence on the design of future CIG systems. More information about the technological innovations can be found in the references cited in the following paragraphs.

Curved Surfaces as the Modeling Unit

Until recently, the basic modeling unit has been edges or polygons. Work now underway suggests that the curved surface is a far more efficient modeling unit than the edge or polygon. Gardner and his associates have developed an approach that uses quadratic surfaces as the modeling unit along with up to six planar surfaces to bound a single quadratic surface (Gardner, Berlin, & Gelman, 1981; Gardner & Gershowitz, 1982; Gardner & Gelman, 1982; Yan, 1980). A similar approach reported by Soland, Voth, and Narendra (1981) employs the "bicubic patch" as the basic modeling unit. Modeling both man-made and cultural features with curved surfaces as the basic modeling unit is much simpler than using edges because very few parameters are required to define a curved surface. Moreover, a more faithful facsimile of many objects can be achieved with curved surfaces than with rectilinear surfaces. This is a particularly important advantage in modeling terrain relief from the Defense Mapping Agency (DMA) source data.

Texture Generation

Texture generation is a technique for increasing scene detail without resorting to ever increasing edge, polygon, or curved surface generation capacity; that is, a texture pattern can be mapped on a surface at a computational cost far lower than that expected by conventional modeling methods. Blin (1978) and Skolmoski and Fortin (1982) describe techniques for generating texture in an edge-based system. Gardner and his associates (see Gardner & Gershowitz, 1982) describe techniques for generating texture in a curved-surface-based system. These techniques provide a highly efficient way to map texture onto the ground plane (flat or curved) and the surfaces of any fixed or moving object. In addition, the technique allows an efficient means of modeling irregular features with dynamic capability, such as trees and grass blown by rotor wash, moving clouds, and billowing dust or smoke.

Computer-Synthesized Imagery

A recently developed technique for high fidelity scene generation is referred to as the Computer Animated Photographic Terrain View (CAPTV) concept (Hooks & Devarajan, 1981). The data base for this technique is generated by a series of overlapping photographs taken with an aerial camera that provides for 360° of azimuth coverage and 100° of elevation. The camera, attached to the underside of an aircraft, has seven lenses and associated mirrors that cast the image onto nine-inch color film. Six lenses capture the oblique views and the central lens covers the straight down vertical view. Photographs are taken at regular intervals along straight and/or cross tracks.

A flying spot scanner is used to scan the nine-inch film to provide a pixel resolution of about 4,000 pixels in both horizontal and vertical directions. The resulting data base is stored on video discs along with the eye point of every scene. As the simulated aircraft flies through the gaming area, the appropriate photographs are retrieved from the storage device for display. The photographs nearest the eyepoint of the operator of the simulated aircraft are "...stretched, skewed, rotated, and translated in a piece-wise continuous mathematical transformation such that the transformed photo would overlay a different photo taken from the operator's eyepoint" (Hooks & Devarajan, 1981, p. 47). In short, the CAPTV device is capable of synthesizing a high-fidelity image of the ground as seen from a point-of-regard different from the point from which any photograph was taken.

A similar approach to computer-synthesized imagery is described by Stickel (1982). He describes a method for synthesizing imagery from four types of components: terrain image, target image, sight reticle pattern, and weapon delivery effect. Graf and Baldwin (1982) describe a hybrid technique in which high resolution photographs are merged with a computer-generated image. This technique is referred to as Computer-Generated/Synthesized Imagery (CGSI). A scene is constructed by placing

individual high-fidelity computer synthesized objects on a specified computer-generated surface.

Improvements to Existing CIG Systems

There are a number of efforts underway that promise to increase the realism of CIG scene elements and to increase the range of tasks/conditions that CIGs can be used to train. Among the most important of these are:

- improved capability to simulate sensor imagery (Hooks & Devarajan, 1981; Faintish & Gough, 1981; Pierce, 1982),
- improved capability to simulate atmospheric phenomena (Allsopp, 1978; Gardner & Gershowitz, 1982; Johnson, 1978; Stenger, Zimmerlin, Thomas, & Braunstein, 1981),
- improved anti-aliasing techniques (Bunker, 1982; Gardner & Berlin, 1980; Gardner & Gershowitz, 1982),
- improved special effects (Booker, Collery, Csuri, & Zeltzer, 1982; Gardner & Gershowitz, 1982),
- improved level-of-detail (LOD) management (AGARD, 1981; Mayer & Cosman, 1982; Stenger et al., 1981), and
- improved CIG data base and data-base construction techniques (Hughett, 1980; Beck & Nicol, 1980; Cunningham & Picasso, 1980; Pierce, 1982).

Developments in all of the above technological areas, and perhaps others as well, may have a major influence on the development and evaluation of candidate scene elements.

Compile Inventory of Candidate Scene Elements[7]

It was judged that the most sensible way to commence formulating hypotheses about what features ought to appear on a CIG display is to examine the real-world features that helicopter aviators refer to when performing the various flying tasks of interest under the various conditions of interest. Accordingly, the purpose of the task discussed here is to compile an inventory of the natural and cultural features that helicopter pilots are known to refer to and to select from this inventory a set of features that can be considered as candidate "elements" for use in constructing one or more CIG display scenes.

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[7]Unless stated otherwise, the term "scene" refers to all computer-generated imagery that may become visible during the performance of a given flying task. So, not all elements of a scene will appear on the display at any given time. The term "scene element" is used here in a very general sense; the term encompasses discrete objects, terrain relief, texture elements, surface-texture elements, and shadows.

One of the main objectives of the second research task described above--Identify Information Requirements/Sources--is to identify the extra-cockpit features that aviators look at in their attempts to obtain the visual information they need to perform a given flying task. The data yielded by this task will be used to construct a "task-by-feature" matrix in which (a) tasks/conditions are listed along one axis of the matrix, (b) features are listed along the other axis of the matrix, and (c) cells within the matrix are checked to indicate the features that aviators sometimes or always refer to when performing the corresponding task.

The initial listing will surely contain several hundred different features--far more than could be or should be modeled and used as CIG scene elements. As a consequence, it will be necessary to reduce the list to more closely approximate the smallest number of features that are necessary and sufficient to perform the full range of flying tasks. This will be done by identifying features that are serving precisely the same function and eliminating from further consideration all but two or three features within such a set. The data from the information requirements analyses, described earlier, will be used to pare down the feature list to a manageable number.

For purposes of illustration, consider the task of flying traffic patterns. When learning to fly VFR traffic patterns at any airfield, helicopter aviators select a feature on the ground to use as a referent in deciding when to initiate the turn for each leg of the traffic pattern. Almost any small natural or cultural feature that is visible and identifiable serves this purpose equally well. So, in developing a display format suitable for training on flying traffic patterns, it is unnecessary to model (for CIG display) buildings, fence rows, ponds, isolated trees, road intersections, and the scores of other features that aviators sometimes use as referents in deciding when to initiate traffic-pattern turns. Models of two or three unique, highly visible features should be adequate for this purpose.

There are some instances in which the nature or difficulty of a task is influenced by the type of feature used as a visual referent in performing the task. The task of masking and unmasking is an example; the difficulty of the task varies greatly as a function of the type of feature being used as a masking object. Aviators report that masking/unmasking behind a gently sloping ridge or hill is far more difficult than masking/unmasking behind a row of tall trees or behind a building. The difference in difficulty is the result of the proximity of features that provide information about the aircraft's deviation from the desired hover position when unmasked. Obviously, features used as a visual referent for the same task cannot be eliminated if they influence the nature or difficulty of the task in a manner such as that described above.

There is considerable uncertainty about how to deal with features that serve as navigational checkpoints. One of the factors contributing

to the difficulty of navigation is that a given map symbol is used to symbolize real-world features whose appearance varies widely. This is true for both natural and cultural features. The use of only one or two different CIG models for any class of feature, such as streams, would result in an unrealistic simplification of the navigation task. And yet, attempting to model a set of features that approaches the range of different appearances found in the real world would be prohibitively costly unless greatly improved modeling techniques are developed.

The compilation of an inventory of candidate scene elements should be performed by a team composed of (a) the experienced aviators who supported the information requirements analysis, and (b) behavioral scientists who are thoroughly familiar with helicopter operations and with the literature on human visual perceptions.

Develop Candidate Scene-Element Designs

The purpose of this task is to develop candidate scene-element designs for subsequent empirical evaluation. As was stated before, the capabilities and constraints that dictate scene-element designs will depend on the technological advancements that are made prior to the time this task is begun. If future CIG systems remain nearly as edge limited as contemporary CIG systems, the goal must be to produce scene-element designs that can be modeled with as few edges as is possible and still provide adequate visual information for effective training. Apparent realism will be a secondary consideration. On the other hand, if technological innovations result in orders of magnitude increases in real-time image generation capacity and modeling efficiency, scene-element realism can be made a more important criterion for evaluating scene-element design.[8] However, it is unlikely that CIG capacity will ever increase to the point that there will be no requirement for attempting to conserve basic modeling units--edges, polygons, quadratic surfaces, or bicubic patches--in developing scene-element designs.

Since the literature contains insufficient data to enable one to predict the relationship between level of realism and aviator judgment accuracy, it will be necessary to develop and assess scene-element designs that vary in their level of realism. One approach to designing scene elements that vary in realism is to give several designers--working individually or as a team--different allotments of modeling units (edges, curved surfaces, etc.) and instruct them to design a specific element, say a tree, with the greatest realism possible without exceeding the allotment of modeling units. Although this is considered a workable approach, it must be acknowledged that the approach does not

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[8]Training effectiveness is the ultimate criterion for evaluating design. Edge requirements and apparent realism are criteria proposed to select prototype models that subsequently will be evaluated in terms of training effectiveness.

ensure that realism will vary as a direct function of the modeling-unit allotment. Indeed, it is to be expected that the innovative use of modeling units could more than offset the differences in the allotment of modeling units. It is also to be expected that, beyond a given point, increased realism of an object simply cannot be achieved by using a greater number of modeling units.

In addition to differences in the allotment of basic modeling units, the model designers should be given different combinations of other capabilities, such as:

- texturing functions--functions that enable the modeler to assign texture to surfaces and to vary the statistical properties of the texture,
- surface reflection functions--functions that enable the modeler to assign diffuse and specular reflectance properties to a surface,
- color functions--functions that enable the modeler to assign color to surfaces/objects or portions of surfaces/objects, and
- translucency functions--functions that enable the modeler to vary the translucency of 3-D object boundaries, 2-D object/area boundaries, and boundaries at which level-of-detail changes.

The capabilities and constraints imposed on the model builder should be formulated through the study of the capabilities and constraints of operational and prototype CIG systems. Consideration should be given to CIG systems in the conceptual design stage only if methods are available to generate dynamic images of the element designs that the new CIG will be capable of producing. In short, there is no reason to develop element designs that cannot be evaluated under dynamic conditions.

There is no one discipline that uniquely qualifies an individual to develop scene designs. Psychologists knowledgeable about human visual perception and computer scientists knowledgeable about CIG functioning certainly should be represented on the design team. In addition, it seems likely that artists and animators could bring valuable knowledge and skills to a design team that most psychologists and computer scientists do not possess.

The following subsection discusses factors that must be considered in modeling CIG features that must be referenced to a map, such as features that are used as checkpoints for NOE navigation. The remaining subsections discuss various issues associated with modeling terrain relief, surface texture, two- and three-dimensional objects, and special effects.

Modeling Generic and Map-Referenced Features

There are some flying tasks that cannot be performed without referring to a map.[9] Nap-of-the-earth navigation, directing artillery fire, and aerial reconnaissance are examples of tasks for which map referencing is essential. Topographic maps also are essential to the planning and coordination of virtually all combat operations. If a CIG system is to be used to train tasks that require aviators to associate map features with their real-world counterpart, the features in the CIG gaming area must be modeled in a manner that enables such associations to take place. Specifically, the features in the CIG gaming area must be modeled such that the relationship between CIG features and the map is the same as the relationship between real-world features and the map.

The map of an area is not designed to be a faithful facsimile of the real-world features that appear in that area. Limitations and constraints imposed by map scale make it impossible to produce a faithful facsimile at a 1:50,000 scale. Just as the map is not a faithful facsimile of the real world, the CIG gaming area cannot be made to be a faithful facsimile of the map. To do so would simplify map-referencing tasks to such an extent that practice with the CIG system would be of no value. Indeed, reinforcing the fallacious expectations of a one-to-one correspondence between map features and real-world features would almost surely lead to negative transfer-of-training.

As a consequence, when modeling what is referred to here as "map-referenced" features, a modeler must be thoroughly knowledgeable about the rules and conventions that cartographers follow in compiling 1:50,000-scale topographic maps. For example, modelers must know that:

- only a fraction of the topographic features in the real world are selected for portrayal on the map,
- the rules and conventions used in selecting features for map portrayal vary from one geographical area to another,
- the features that are selected for portrayal are represented on the map with point or linear symbols that may be generalized in shape, exaggerated in scale, or displaced in position in accordance with formal rules and informal conventions that govern map compilation,

[9] Helicopter training operations within the U.S. are almost always performed with a 1:50,000-scale topographic map produced by Defense Mapping Agency (DMA) cartographers. Combat and training operations outside the U.S. may be performed with topographic maps compiled by foreign cartographers. The design similarity of foreign maps to maps compiled by DMA personnel varies greatly from one country to another. The differences of primary concern are differences in the selection and classification of features for map portrayal.

- a cluster of, say, three standard building symbols (solid black square) may be used to depict a cluster of, say, seven real-world structures that are spaced so closely that they cannot be portrayed individually without overlapping the symbols,

- small bends in roads and stream beds cannot be portrayed because of limitations imposed by scale, and

- the same solid blue line is used to portray all perennial streams with a bank-to-bank width less than 25 meters.

The above represent just a fraction of the systematic differences between mapped features and their real-world counterpart. In order to model a CIG gaming area that will prove effective in training map-referencing tasks, the modeler must produce the same systematic differences between the map and CIG features.

Terrain Relief Modeling

Many of the tasks listed in Appendix A can be trained effectively with no elevated landforms whatsoever. For example, a flat textured ground plane should be adequate for training such basic tasks as takeoff to a hover, hovering turns, climbs and descents, traffic pattern flight, approaches, landings, and perhaps others as well. For tasks such as these, the only utility of terrain relief would be to "decorate" the scene or to eliminate an unrealistically clear horizon line.

Other tasks require terrain relief but can be trained effectively with "generic" terrain relief; that is, displayed terrain relief does not have to be associated with terrain relief portrayed on a map. Examples of tasks that clearly could be trained with generic terrain relief are pinnacle operations, ridgeline operations, slope operations, and NOE decelerations. Most CIG system vendors have assumed that effective training on contour and NOE flight can be accomplished with generic terrain relief. This assumption is probably valid for aviators of high-speed fixed-wing aircraft but is questionable for helicopter aviators. As was stated earlier, helicopter aviators have acquired a high level of perceptual and aircraft-handling skills prior to the time they commence training on contour flight and NOE flight. The extent to which aviators' perceptual and aircraft-handling skills would be further enhanced by practicing contour and NOE flight with generic terrain relief is not known. Anecdotal evidence from discussions with experienced aviators indicates that the most critical deficiency at this stage of training is in the cognitive skills required to navigate accurately during contour and NOE flight.

There are a substantial number of tasks that clearly cannot be trained using generic terrain relief. Training on NOE navigation is a critically important skill that requires the modeling of map-referenced terrain relief. Other tasks requiring map-referenced terrain relief

include target handoff, the direction of artillery fire, aerial reconnaissance, and combat engagements by a multiple aircraft team. The decision to train such tasks using a CIG system imposes severe requirements for modeling terrain relief. First it will be necessary to use the DMA Digital Landmass System (DLS) data base or another data base to model terrain relief. The DMA data base is the only source of data on terrain relief for which topographic maps are available.

Second, the terrain relief must be modeled such that relatively small attributes of landforms can be perceived in the CIG image. To maintain accurate geographic orientation at low altitudes, the helicopter crewmen must be able to associate small terrain features to their counterpart on the map. Small draws, small spurs, small saddles, the steepness and shape of slopes, and small stream beds are examples of features that aviators must be capable of associating with the map in order to navigate accurately at NOE altitudes. Clearly, it is not enough to display large landforms, such as wide valleys and large ridgelines, in the CIG scene.

Finally, it will be necessary to model several different types of terrain relief. Training in one type of terrain does not fully prepare an aviator to perform map-referenced tasks in a different type of terrain. For instance, navigation training in an area with low rolling hills does not fully prepare an aviator to navigate in mountainous terrain.

Texture Modeling

In the past, texturing of surfaces in a CIG scene has been accomplished by modeling two-dimensional objects (a uniform grid, irregularly shaped polygons, etc.) and mapping them onto the surface of the ground plane or the surface of three-dimensional objects appearing in the scene. Texturing of the ground plane also has been accomplished by modeling three-dimensional objects, such as trees or structures, and mapping them onto the surface of the ground plane. These techniques are costly in terms of both modeling time and CIG computational capacity. For example, Sinacori has calculated that about 17 million discrete texture elements (Sinacori used trees as texture elements in his computations) would be contained within a circle one mile in radius if the texture elements were separated by an average of 15 feet.

The next generation of CIG systems almost certainly will provide modelers with far more efficient techniques for mapping texture onto the surface of the ground plane and the surfaces of both stationary or moving objects. The most advanced texturing techniques developed to date employ mathematical functions to modulate the shading intensity of a surface. For detailed discussions of these techniques, see Gardner and Gershowitz (1982) and Skolmoski and Fortin (1982). Such techniques will enable CIG scene modelers to generate a wide variety of textures varying from the regular texture pattern of a brick wall to the highly irregular texture pattern formed by the leaves of a tree.

It seems probable that mapping texture onto CIG surfaces will serve to increase the veridicality of judgments of surface slant/curvature, distance, and relative velocity. However, the current perception literature lacks the information that is needed to specify the characteristics of an effective texturing function or to estimate the benefits that would result from texturing surfaces that appear in a dynamic CIG scene. Based upon a comprehensive review of the perception literature, Stenger and his associates summarize the germane literature as follows:

> Research on static texture has generally found that while regular textures are effective in conveying surface slant to observers, irregular textures are definitely less effective and sometimes completely ineffective (Degelman & Rosinski, 1976; Gibson, 1950; Gibson & Gibson, 1957; Levine & Rosinski, 1976; Newman, 1972; Newman, Whinham, & MacRae, 1973; Rosinski & Levine, 1976). Although research with random textures in dynamic scenes has shown good correspondence (usually with some underestimation) between displayed and judged slants (Gibson, Gibson, Smith, & Flock, 1959), this accuracy appears to be based on the velocity gradient information carried by the texture rather than on the texture gradient per se (Braunstein, 1968). Farber and McConkie (1979) suggest that the velocity gradient may reveal degree of slant range while the texture gradient reveals direction, but this hypothesis remains to be tested. This issue is part of an unanswered question that is important to the design of CIG displays: Is texture effective primarily (or exclusively) as a carrier of velocity information, or does the texture gradient itself provide information that reduces the ambiguity of surface definition? (Stenger et al., 1981, p. 75)

An extensive psychophysical research program is needed to determine how best to use two-dimensional texturing on CIG surfaces. Also, research is needed to determine the effects of three-dimensional texture--singly and in combination with two-dimensional texture--on judgments of surface slant/curvature, distance, and relative velocity. A detailed discussion of the requirements for research on surface texturing is presented in the following section.

Object Modeling

The term "object" is used here to refer to any two-dimensional or three-dimensional form other than terrain relief, surface-texture elements, and shadows.[10] The modeling of candidate objects must

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[10]As was stated in footnote 7, the term "scene elements" encompasses "objects" as well as terrain relief, surface-texture elements, and shadows.

commence with a study of the function served by each item listed on the object inventory compiled during the information requirements analysis. The function served by an object may be any one. or more of the following:

- scene decoration--an object that contributes to scene realism but has no direct impact on perceptual judgments made as a result of viewing the scene,
- position referent--a stationary object that an aviator uses as a referent in positioning his aircraft in the x, y, and z axes (airfield, confined area, traffic pattern referents),
- perceptual calibration referent--an object of known size that aviators use to establish the scale of a CIG scene,
- perceptual learning referent--an object that must be present in the scene in order for requisite perceptual learning to take place,
- generic target for weapons training--a stationary or moving object, <u>not</u> referenced on a map, that serves as a target for weapons training,
- map-referenced target for weapons training--a stationary object that serves as a target for weapons training and that must be referenced to a standard topographic map,
- generic target for target detection/identification training--a non-map-referenced object, stationary or moving, that is used in training aviators to detect and/or identify targets,
- map-referenced target for target detection/identification training--a map-refenced, stationary object that is used to train aviators to detect and/or identify targets, and
- navigation checkpoint--an object, which may or may not be portrayed on the map, that serves as a potential navigation checkpoint.

The functions served by an object have a major impact on the manner in which the object must be modeled. For example, consider the modeling of a man-made structure. A structure that serves only as scene decoration or as a position referent can be nearly any size and shape. If it serves as a position referent, it need only be unique enough to enable aviators to distinguish it from other structures in the CIG data base. If the structure serves as a perceptual calibration referent, the aviator must be able to associate it with a real-world structure whose size is known; or, the aviator must be instructed on the exact dimensions of the structure. A structure that serves as a perceptual learning referent must be modeled such that the perceptual learning resulting from practicing with the CIG structure will generalize to similar real-world structures. Establishing what features a CIG object must have to ensure perceptual learning, of course, is one of the most critical and illusive tasks in this program of research.

Nearly any type of structure can serve as a generic target for weapons training. However, if the structure is one that must be related to its map portrayal, the shape and size of the object will be dictated, to some degree, by the symbol used to depict the object on the map. For instance, if the structure is portrayed with a standard building symbol, it must be a permanent dwelling or a commercial building whose largest dimension does not exceed about 25 meters. If the structure is portrayed to scale on the map, the corresponding structure modeled for CIG display must have the same dimensions and outline-shape as the symbol. A structure that serves as a navigation checkpoint must be modeled in the same manner as a structure that serves as a map-referenced target.

Probably the most stringent modeling requirements are those of objects that serve as a target for target detection and/or identification training. For target detection training, the modeler must design the object and the background against which it is viewed in a manner that presents the aviator with a realistically difficult discrimination task. This will require careful modeling of the brightness contrast, color contrast, reflectance, and image complexity of both the object and its background. An object that serves as a target for target identification training must be modeled in sufficient detail to (a) enable the aviator to differentiate the object from other CIG objects of the same class, and (b) ensure that the target identification training will generalize to real-world situations.

The required specifications for an object model include: the equations that determine the geometric shape of the surfaces, parameters that determine the reflective properties of each surface (total reflectance and fraction of diffuse and specular reflectance), parameters that dictate the color (hue and saturation) of each surface, and modulation functions that determine the texturing of each of the object's surfaces.

Such specifications must be developed for both direct view and one or more sensor views of the object. Low-light-level TV is so similar to the direct view that additional parameters need not be added to the data base; the elimination of color and the reduction of resolution should be the only requirements for modifying the basic direct-view model of an object. However, the Forward-Looking Infrared (FLIR) image of an object can be and usually is markedly different from the direct-view image of the same object. Gardner and Gershowitz discuss one approach to generating FLIR images of objects (Gardner & Gershowitz, 1982, pp. 193-197). They identify the global Infrared (IR) parameters that must be specified for each object and presents equations for computing intensity for (a) IR day images of passively emitting objects, (b) IR day images of actively emitting surfaces, (c) IR night images of passively emitting objects, and (d) IR night images of actively emitting surfaces.

An altogether different approach to producing FLIR imagery has been developed by Hooks and Devarajan (1981). This approach employs monochrome infrared aerial photographs stored in a large random-access video data base. The data in the video data base are processed by a

computer to generate the imagery from any point of regard. If this approach is employed, there would be no need to model FLIR imagery from a numerical data base such as the DMA Digital Data Base.

Special Effects Modeling

Consideration must be given to the modeling of at least four classes of special effects: shadows, atmospheric phenomena, weapons effects, and lights. The following paragraphs comment briefly on the relevance of each of these classes of special effects for a CIG designed solely for training helicopter aviators.

For centuries, artists have recognized the role of shadows in producing the illusion of depth on a two-dimensional surface. Yet, not a single study has been located in the literature that has been designed to assess the impact of shadows on the veridicality of perception of a computer-generated image. Even the classical perceptual literature on the role of shadows is extremely limited. The few studies in which shadows were investigated as an independent variable used simple photographs or drawings as stimuli (Cross & Cross, 1969; Hess, 1961; Yonas, Goldsmith, & Hallstrom, 1978). Although these studies confirmed that shadows have a major impact on perception, they provide insufficient information to draw any inferences about the importance of shadows in a dynamic CIG scene.

In the real world, shadows may provide or obscure significant cues. The detection and identification of objects may become far more difficult when they appear in the shadow of another object--especially at low sun angles and during periods of darkness when moonlight isn't intense enough to create shadows. On the other hand, shadows may aid the detection of moving targets and may facilitate the perception of the shape of complex landforms. There is anecdotal evidence that shadows in a CIG scene are sometimes required to avoid perceiving three-dimensional objects as "floating" above the ground plane on which they are located.

The method used to generate shadows is certain to have a major impact on CIG costs. Storing of objects as shadows would nearly double the size of the CIG system data base, since every three-dimensional object casts a shadow. Conversely, generating shadows on-line would nearly double the computational load of the CIG system. If these two techniques were the only ones available, it is doubtful that the benefits realized from shadow generation would offset the cost. So, there is a critical need to develop more efficient techniques for modeling and generating shadows. Gardner and Gershowitz discuss the problem of shadow generation and describes several techniques for representing the essence of shadows with the least possible overhead in data storage and computational load (Gardner & Gershowitz, 1982, pp. 54-76); Gardner and Gershowitz consider at least two of these techniques to be cost effective. The development of highly cost-effective shadow-generation techniques could be a difficult and time-consuming job, so

the military should continue to support efforts to develop efficient methods for generating shadows in CIG scenes.

The second class of special effects--atmospheric phenomena--is important for two reasons. First, atmospheric phenomena must be modeled in order to create aerial perspective--an often cited cue to distance whose role in perception has yet to be determined. Secondly, atmospheric phenomena must be generated in order to use CIG systems to train aviators to fly during periods of degraded visibility. Atmospheric phenomena that must be generated to cover the full range of visibility conditions in which helicopter aviators must be able to operate include:

- haze,
- fog (solid and broken),
- clouds (cloud layers and 3-D clouds),
- dust,
- smoke,
- rain, and
- snow.

The models used to generate atmospheric phenomena can vary considerably in their complexity and, therefore, their cost in computational time (see Allsopp, 1978; Gardner & Gershowitz, 1982; Stenger et al., 1981). However, no empirical data are available on the relationship between training effectiveness and the complexity (fidelity) of these models. Thus, there is a need to develop models that vary systematically in their fidelity and to assess the relationship between model fidelity and training effectiveness.

Weapons effects are a third type of special effects that must receive attention. The most important function served by weapons effects is to provide feedback to crew members about the accuracy and the result of their weapons firings. Feedback on the destructive force of the weapon and the proximity of the hit may be provided in the form of target-structure alteration, charring, fire, smoke, or numerical scores. Special effects also can be used to depict weapon trajectory. Highly realistic weapons effects, such as altering the structure of a target, may contribute to greater user acceptance, but it is unlikely that they will result in more effective training than less realistic effects. Hence, it is expected that the degree of realism that proves most suitable will depend primarily on the modeling and computational costs associated with the weapons effects generation.

The final class of potentially relevant special effects is lights. Designers of CIG systems have considered the modeling of both natural light sources (sun, moon, and stars) and cultural light sources (omnidirectional, unidirectional, rotating, and flashing). The modeling of cultural light sources has received considerable attention in the development of CIG systems for use in training commercial airline aviators. The resulting CIG scenes have proved to be highly effective for training on night landings. Cultural lights are less important for training helicopter aviators because, in combat conditions, cultural

lights cannot be expected to be available in takeoff and landing areas and cannot be expected to serve as reliable checkpoints for night navigation.

The visual information requirements analysis of night operations should provide at least preliminary information about the need for the generation of light sources. Once decisions have been made about the types of light sources that need to be generated, additional research will be required to determine the characteristics and geographical placement of each type light source to be generated.

In addition to the generation of continuous light sources, attention must be given to the need for generating momentary light sources required to simulate muzzle flashes of enemy weapons during both daytime and nighttime combat operations.

Design and Conduct Psychophysical Experiments

The purpose of this task is to evaluate empirically the relative effectiveness of the candidate scene-element designs developed during the course of the preceding task. It is expected that the findings of the psychophysical research will provide insights about how to further improve the design of some scene elements. In fact, it may be necessary to iterate through the design and evaluation research process several times before near optimal designs are produced.

General Research Approach

In the final analysis, training effectiveness is the only true measure of the effectiveness of the scene content of a CIG display. However, at the outset of this research, there is such a large number of design options that it would be an enormously expensive undertaking to evaluate every option through transfer-of-training experiments. An alternate approach is to conduct psychophysical studies to assess the relative effectiveness of alternate scene-element designs and, subsequently, to conduct transfer-of-training studies to determine whether the scene-element designs that proved best in the psychophysical studies result in effective training transfer. This approach assumes only that psychophysical procedures can be used to assess the <u>relative</u> effectiveness of scene-element designs for training; no conclusions about <u>absolute</u> training effectiveness are made until the transfer-of-training experiments have been completed.

Recommended Research Procedures

The types of judgments that helicopter aviators must make varies so greatly from one task to another that there is no single psychophysical research procedure that is suitable for assessing judgment

accuracy for the full range of flying tasks. A study of the tasks listed in Appendix A led to the conclusion that helicopter flying tasks can be classified into three categories with respect to the types of judgments that are most critical to the successful performance of the tasks. A different research procedure is required for each of the three categories of tasks.

All of the research described below assumes the availability of a CIG system that is capable of generating the full range of scene-element designs. If some scene-element designs exceed the capability of the CIG system used to conduct the research, it may be possible to develop alternate ways to produce the stimulus material needed to evaluate the designs. One potentially feasible technique is to generate the required imagery in non-real-time and use the imagery to produce a motion picture or video tape that would simulate real-time conditions. Animation is another potentially feasible approach. Even still photographs have been used successfully to investigate scene content requirements (deGroot, 1981; DeMaio & Brooks, 1982; Eisele et al., 1976; Roscoe, 1977).

Judgment of flight parameters. One category of tasks requires aviators to use information gleaned from a dynamic, extra-cockpit scene to make judgments about one or more of the following:

- aircraft position (vertical, lateral, and longitudinal) relative to one or more extra-cockpit referents,
- rate of change of aircraft position,
- aircraft attitude (roll, pitch, and yaw) relative to one or more extra-cockpit referents, and
- rate of change of aircraft attitude.

A suitable research procedure for this category of tasks must provide valid and sensitive measures of the accuracy of position and attitude judgments as scene-element design is varied systematically. To ensure maximum validity, subjects must be required to make their judgments with a dynamic rather than a static display. To ensure maximum sensitivity, the subjects' judgments should not be confounded with non-visual skills, such as aircraft handling skills and cognitive skills. The procedure that is recommended is similar to the classical psychophysical method sometimes referred to as Method of Adjustment (Edwards, 1950) and sometimes referred to as Method of Average Error (Guilford, 1954). The procedure requires that the subject be given direct and independent control of each of the three position parameters and each of the three attitude parameters. The subject would use the controls to (a) adjust parameters to a prescribed value, (b) maintain parameters at a fixed value in the face of a realistic forcing function, (c) adjust rate of change of parameters to a prescribed value, or (d) maintain parameters' rate of change in the face of a realistic forcing function.

Each task classified into the first category must be analyzed to determine the critical parameters that must be judged, the "standard" (command value) for each parameter, and the size of the error tolerance for each type of judgment. For example, an analysis of the task "Takeoff to a Hover" shows that an aviator must be capable of the following perceptual judgments: (a) judge when altitude is at a value of four feet (skid height), (b) detect deviations of one foot or more from an altitude of four feet, (c) detect deviations of five degrees or more from a prescribed heading, and (d) detect forward or lateral deviations from a fixed position that exceed two feet. This suggests the need for psychophysical studies to assess the effect of scene-element design on a subject's ability to adjust altitude to a value of four feet, null a forcing function as necessary to maintain an altitude of four feet, null a forcing function as needed to maintain heading at a prescribed value, and null forcing functions as necessary to maintain a fixed lateral and longitudinal position.

Once all the tasks in the first category have been analyzed in this manner, it will be possible to develop, for each parameter, a table that lists the values of standards (positions and/or rates) to be judged, the error tolerance for each standard, and the type of judgment required for each standard (adjust parameter to standard or detect deviation from a standard). Together, such tables would specify the full range of judgments that may be influenced by the scene content of a CIG display. In designing the psychophysical experiments, it will be necessary to select a small, representative sample of flight parameter judgments to use in assessing the relative effectiveness of alternate scene-element designs.

Extra-cockpit feature detection/identification. The critical element of a second category of tasks is the detection and/or identification of extra-cockpit features. Some tasks in this category require only that the aviator recognize a clearly visible object as being one of a given class or one that has been seen before and adopted as a position referent. These tasks are referred to as short-range object recognition tasks. Research is required to evaluate alternate designs for objects that are to be used to provide training on short-range object recognition. The procedure recommended for this research is a simple one: measure object recognition accuracy and response latency as a function of point-of-regard viewing range and object background.

Other important tasks included in the second category are long-range target detection and identification. It seems highly likely that nothing short of high-fidelity CIG scene elements would result in effective training on target detection and identification. Although it would be possible to develop realistically difficult target detection and identification tasks using abstract targets and backgrounds, it seems unlikely that training with abstract scene elements would transfer positively to a real-world setting. In fact, training with abstract scene elements may very well result in perceptual sets that are

counterproductive. However, these views are based on suppositions and empirical research is required to resolve the issue.

It seems probable that much could be learned about the relationship between scene-element design and both short-range object recognition and long-range target detection and identification from studies using stimuli produced from photographs and artists' drawings of selected scene elements. It is recommended that the feasibility of such research be evaluated and, if feasible, pursued until a suitable CIG system becomes available.

Map/real-world feature association. The critical aspect of the third category of tasks is that of associating extra-cockpit features with their counterpart on a topographic map. The criterion for evaluating the design of all scene elements other than terrain relief is the ease and accuracy with which a trained aviator can identify the map symbol that would be used to portray the object on a standard 1:50,000-scale topographic map. Accordingly, the evaluation of alternate scene-element designs for the third category of tasks can be accomplished by merely displaying each candidate scene-element design and requesting trained aviators to examine the feature and indicate on a map legend the symbol that most likely would be used to depict that feature on a map.

The technique used to display terrain relief must be evaluated by determining the ease and accuracy with which trained aviators can associate landforms appearing on the CIG display with their counterpart on the map. To accomplish such an evaluation, it is necessary to have an accurate CIG data base for a geographic area that has been mapped at a scale of 1:50,000. One procedure for evaluating alternate techniques for displaying terrain relief is to require experienced aviators to examine terrain relief appearing on a CIG display and select from four or five alternatives the location on the map from which the displayed terrain is visible. A second technique is to assess the accuracy with which trained aviators can maintain geographic orientation using only the CIG displayed terrain relief and a map. With this procedure, the simulated aircraft would be flown along a pre-selected route and the subject would be required to draw the flight path on the map.

Develop Candidate CIG Scene Models

The purpose of this task is to apply the insights and data accumulated to this point in the program in developing a set of CIG scene models for subsequent empirical evaluation. The specification for each scene model must define at least the following:

- the size of the area covered by the model,
- the elevation of terrain relief at each point throughout the model,
- the types and locations of the topographic features that appear on the terrain surface,

- the number of levels-of-detail and the slant range at which each level-of-detail appears/disappears,
- the types of texturing that appear on each ground plane area, and
- the exact design parameters for each three-dimensional topographic feature (including the texturing of object surfaces).

Scene models that have been developed for training fixed-wing aircraft aviators have had several "levels-of-detail." That is, the scene content varies as a function of viewing range. As viewing range to an area increases, the elements that comprise the scene tend to become larger, less detailed, and less dense. Conservation of computer computational capacity is one reason for designing CIG imagery with different levels-of-detail. Another reason is that a high level-of-detail simply cannot be perceived from large distances. More than one level-of-detail will be required for CIG imagery developed for helicopter operations. However, because most helicopter flight occurs at low altitudes, fewer levels-of-detail will be required than for fixed-wing operations. Once the required number of levels-of-detail has been determined, it will be necessary to develop scene models for each level-of-detail.

The end product of this task is a set of scene models that vary along a dimension of training capability. The initial step in accomplishing this task is to define what is judged to be the least costly scene model that would have a significant training benefit. The next step is to define a second scene model that has a training capability that is judged to be significantly greater than the base model. This procedure will be repeated--with each new scene model having an incrementally greater training capacity than the preceding scene model--until a scene model is developed that has the greatest training capability that the CIG technology will allow. It is expected that between six and 12 scene models will be required to cover the full continuum of training capability.

At this point in the project, little will be known about training effectiveness as such. So, judgments about the training capability of a given scene model will have to be based more on predictions about number of different tasks that can be trained with the scene model than predictions about the effectiveness with which a given task can be trained. Without question, considerable subjectivity will enter into the judgments. However, the previous tasks should yield a considerable amount of information and performance data that will bring some degree of objectivity to the judgments. First, much will be known about the information that aviators must extract from the extra-cockpit scene in order to perform each training task. Secondly, the psychophysical experiments will serve to identify scene-element designs that enable aviators to make germane perceptual judgments and will provide in-depth knowledge about the accuracy with which the perceptual judgments can be

made. Finally, an updated assessment of CIG technology will provide the information needed to make judgments about the feasibility of generating, in real time, the scene elements that comprise a given scene model.

Once the candidate scene models have been developed, each member of a team of subject matter experts will be required to identify, for each training task, the least complex/costly scene model that will provide effective training. The subject matter experts also will be required to identify tasks that, in their opinion, cannot be trained with each scene model.

Identify Critical Parameters of Display Subsystem

It is generally recognized that the effectiveness of an entire CIG system can be influenced by qualities of the display subsystem, such as: field-of-view, resolution, brightness, contrast, distortion, tonal range, and color rendition. It would be of academic interest to investigate the relationship between each display quality and training effectiveness, but to investigate display qualities as independent variables, along with scene models, would greatly increase the cost of this program of research. It seems likely that cost considerations will dictate that the research be limited to display subsystem components that have a significant impact on total system cost. This assumption is explained more fully below.

There have been continuing efforts to develop display components that improve the quality of the image, and there is no reason to believe that such efforts will cease in the foreseeable future. It can be expected that, in some instances, improvements in image quality can be achieved with new hardware components that cost little more than the older components. In such instances, no research is required to determine that the new component is more cost effective than the old one. It is only when new components cost appreciably more than the older ones that research is required to determine whether the added training benefits of the new component outweighs its added costs.

Thus, the purpose of this task is to identify display components whose cost effectiveness cannot be assessed without data on the component's training effectiveness. If this research program was initiated at the time of this writing, it probably would be necessary to collect training-effectiveness data to assess the cost effectiveness of such components as light valve projectors, Area-of-Interest (AOI) display systems, and large field-of-view optics. By the time this research program is initiated, however, the production cost of these components may be so small that no research will be required to establish their cost effectiveness.

Develop Efficient Instructional Methods

The various visual-system configurations must be evaluated in terms of training effectiveness, so it is necessary to develop methods to use in training the individuals who serve as subjects in this research. It is essential that training methods be used that are known to be effective; otherwise, the deleterious effects of ineffective training methods could totally mask important differences between visual-system configurations. A literature search revealed only a few studies aimed at the development and/or evaluation of flight simulator training methods. Even fewer studies were located that addressed the question of training effectiveness for simulators equipped with a CIG display. The few studies that have addressed training methods in flight simulators have limited value for present purposes because they dealt with fixed-wing aircraft.

Since little is known about how best to train Army aviators in flight simulators equipped with a CIG system, it is recommended that a systematic program of research on this important topic be initiated as soon as possible. The recommended research program is described in detail later in this section. It is assumed that much of the research on instructional methods must be completed before it will be possible to initiate research to evaluate the training effectiveness of alternate visual systems.

Design/Conduct Experiments on Visual-System Configurations

It is impossible to specify at this time the design of the specific experiments that will be required to assess the candidate visual-system configurations. However, it is possible to discuss critical requirements that must be met by the research and to discuss some of the factors that make it difficult to design and conduct research that will fulfill these requirements.

A key requirement is that the research be designed to provide the transfer-of-training data and the continuation-training effectiveness data that are needed to make a quantitative assessment of the cost effectiveness of alternate visual-system configurations. As has been stated earlier, transfer-of-training experiments disrupt the training system and are both costly and time-consuming to conduct. Research to assess the utility of simulators for maintaining the skills of trained aviators may be even more disruptive and costly than transfer-of-training research. The reason is that a valid assessment of the utility of simulators for skill maintenance is not possible without restricting or curtailing, for the duration of the research, the aircraft flying time of the aviators who serve as subjects. For obvious reasons, command personnel at all levels are reluctant to support such research. Because of the extremely high cost of transfer-of-training and continuation-training effectiveness research, every attempt must be made to reduce the number of conditions that must be investigated with these methods.

A second important requirement of this research is that training transfer and continuation-training effectiveness be examined on a task-by-task basis. There are two reasons for this requirement. First, there is certain to be a powerful interaction between tasks and visual-system configurations. The visual systems will vary in the number of tasks for which training can even be attempted. By design, the lower cost CIG scene models will lack the scene elements needed to train some tasks. The visual systems also may vary in the relative effectiveness with which a given task can be trained. That is, for tasks that can be trained on two or more of the visual-system configurations, the rate of skill acquisition may vary widely from one configuration to another.

It is essential that task-by-configuration interactions be taken into account when assessing the cost effectiveness of alternate visual-system configurations. Computations of the cost effectiveness of a given visual-system configuration should be based only on the tasks that can be trained reasonably effectively with that configuration. Otherwise, it is predetermined that the lower cost configurations will be less cost effective than the higher cost configurations. Ideally, training-effectiveness data would be available to calculate the cost effectiveness of a visual-system configuration assuming training on different combinations of tasks.

A second reason for the need to examine training effectiveness on a task-by-task basis stems from the fact that the effectiveness of training on any given flying task may be influenced greatly by the types of tasks trained previously and the effectiveness with which these tasks have been trained. Helicopter flying tasks are trained in a fixed sequence because it is assumed that skills on some tasks cannot be acquired effectively until other, more basic, tasks have been mastered. If an adequate level of a basic skill is not acquired, the training on more advanced tasks, which are dependent on that basic skill, will appear ineffective. For example, training on hovering turns would appear ineffective if the student has had inadequate training on stationary hover. A failure to consider the interdependencies among tasks could result in serious misinterpretations of the data which, in turn, would lead to erroneous conclusions about the cost effectiveness of alternate visual-system configurations.

The considerations discussed above suggest a need to conduct at least two different types of studies at this stage in the research program.

In-Simulator Skill Acquisition Studies

The objective of the first type of study is to examine the rate and level of skill acquisition in the simulator. Although skill acquisition in the simulator does not necessarily mean that an aviator trainee is acquiring transferable skills, it appears reasonable to assume that a lack of improvement of performance in the simulator is an

indication that the aviator trainee is not acquiring transferable skills. If this assumption is valid, task-by-task data on the rate and level of skill acquisition in the simulator should serve to identify (a) tasks that cannot be trained effectively with a given visual-system configuration, (b) instances in which the simulator training time allocated to a given task is not great enough to permit the aviator trainee to become fully proficient at that task, and (c) training that is ineffective because the aviator trainee failed to acquire important prerequisite skills. Data of potential value include:

- the rate of skill acquisition in the simulator relative to the rate at which the same skill is acquired in the aircraft,
- the level of skill achieved by aviator trainees relative to the simulator performance level of fully trained aviators, and
- the extent to which training on lower fidelity visual-system configurations transfer to performance with the highest fidelity visual-system configuration investigated (see Westra, 1982, for a discussion of in-simulator transfer-of-training).

Transfer-of-Training Studies

As indicated earlier, the objective of the second type of study is to measure the extent to which training in the simulator transfers to the aircraft. There is a need to measure the transfer of both skill acquisition and skill maintenance training. The methodology used in traditional transfer-of-training research is discussed in detail by Roscoe and his associates (Roscoe, 1980). However, there are two important issues that are not addressed either by Roscoe or other researchers. The first issue is the measurement of training transfer on a task-by-task basis. Casual consideration suggests that the relative task-by-task transfer effectiveness of different visual-system configurations could be measured by first training an aviator to criterion in the simulator and then determining the number of practice iterations in the aircraft the aviator requires to reach a criterion level of performance in the aircraft. Upon closer inspection, however, it becomes apparent that this approach has numerous methodological and practical problems that must be overcome before it can be recommended.[11]

The second issue concerns the methodology for assessing the effectiveness of simulator training for skill maintenance. Not one study was located in the literature that sheds light on the best methodology for assessing the continuation-training effectiveness of simulators. The development of a suitable methodology is complicated by the general lack of knowledge about the rate at which different types of flying skills decay if not practiced. It seems reasonable to assume

[11]See page 61 for a detailed discussion of the problems associated with measuring training transfer on a task-by-task basis.

that a suitable methodology will require that experimental groups be employed as necessary to measure the main effects and interactions of at least the following variables:

- the initial skill level of the aviator,
- the length of the no-practice period, and
- the type and amount of simulator practice the aviator receives.

Before research is initiated to measure the effects of visual-system configuration on continuation-training effectiveness, it will be necessary to conduct preliminary research to establish appropriate values for the length of the no-practice period(s) to be investigated and the amount of simulator training to be administered at the end of the no-practice period. Obviously, the relative effectiveness of different visual-system configurations could not be assessed adequately if aviators did not refrain from practice long enough for their flying skills to decay appreciably. Similarly, the effectiveness would be reduced if aviators received too much or too little simulator training at the end of the no-practice period.

Identify Most Cost-Effective Media Mix

Once the research to assess the training effectiveness of alternative visual-system configurations has been completed, it is recommended that the research results and other required data be used in an analysis to identify the most cost-effective mix of training devices for accomplishing skill acquisition training (IERW and transition) and continuation training. A less complicated and less costly analysis could be conducted to determine only the relative cost effectiveness of alternative visual-system configurations. However, limiting the cost-effectiveness analysis to visual-system configurations almost surely would lead to erroneous decisions about the optimal allocation of training resources--particularly with respect to part-task training devices.

Even now, it is possible to conceptualize low-cost, part-task training devices that may be effective for training some of the flying tasks that impose the greatest demands on a CIG-based visual system. Target detection/identification and NOE navigation are the two prime examples. As the research on visual systems is conducted, the researchers undoubtedly will conceptualize other potentially effective training alternatives.

Figure 3 shows that four other tasks must be accomplished in order to compile the data and refine the methodology for optimal mix analyses.

Compile Visual-System Cost Data

First, it is necessary to compile accurate cost data for each visual-system configuration. These data must include, for each visual-

system configuration, both the life-cycle cost of the hardware and the cost of compiling the data base required to support each visual-system configuration. The types of cost data that must be compiled is described in the Department of Defense Life Cycle Costing Guide (DoD, 1973). Generally, the requirements include "initial" costs (procurement costs) and "consequential" costs (cost of ownership, support costs, or operations and maintenance costs). Cost data for individual components of the display subsystem, the image generator subsystem, and the data-base subsystem would be useful for identifying cost drivers, but component costs are not essential for performing the recommended cost-effectiveness analyses.

It is expected that the most difficult part of compiling visual-system cost data will be that of estimating the cost of a CIG that is specifically designed to generate the imagery for one or a set of prescribed scene models. It is extremely unlikely that any CIG available on the market at the time the research is completed will be found to be suitable. Even though an existing CIG may be capable of generating the required scene content, it is probable that the device would have unneeded capabilities and capacity that the Army would be reluctant to pay for. If this expectation proves valid, it will be necessary to estimate the cost of a CIG that has not yet been designed. No easy solution to this problem is apparent at this time. In the absence of historical data, the only alternative may be to contract with CIG vendors to produce a preliminary design in sufficient detail to enable estimates to be made of the life-cycle costs.

Develop Improved Cost Models

Second, it will be necessary to develop improved models for assessing cost effectiveness. The primary need is for cost-effectiveness analysis models that (a) take into account certain costs and benefits not considered by existing models, and (b) identify the most cost-effective mix of training media (including the aircraft, simulators, procedures trainers, part-task trainers, and classroom instruction) for aircrew training on specific tasks. This need is discussed in detail in a later subsection of Section II (entitled Cost-Effectiveness Analysis Models). The only point that needs to be made at this point is that substantial progress has been made in developing linear optimization models for use"in evaluating flight-training systems (Marcus, Patterson, Bennett, & Gersham, 1980). Linear programming techniques are ideally suited to the problem of evaluating the cost effectiveness of all permutations of large numbers of training media options, each of which has different training capabilities and costs.

Compile Data on Costs of Training in the Aircraft

Third, it will be necessary to compile up-to-date data on the cost of training each task in the aircraft. Presumably, the Army maintains

accurate data on flying-hour costs for each aircraft type, but it will be necessary to conduct additional research to derive accurate estimates of the amount of flying time the average student requires to learn each training task.

Compile Data on Training Effectiveness and Cost of Alternate Training Methods/Media

Finally, it will be necessary to compile data with which to estimate the training effectiveness and the cost of ground-based training methods and media other than CIG based flight simulators. Again, cost- and training-effectiveness data must be derived for individual flying tasks. Data for existing components of the training system can be derived by analyzing historical cost data; transfer-of-training research will be required to assess the training effectiveness of existing components of the training system. It will be more difficult to estimate the costs and training effectiveness of potentially useful alternatives to aircraft or simulator training that have been conceptualized but not yet developed. In such cases, it will be necessary to either develop and evaluate prototypes of candidate devices or to use the best information available to derive cost- and training-effectiveness estimates.

Summary

In summary, the analysis to identify the most cost-effective media mix requires inputs from the tasks listed below and shown schematically in Figure 3:

- Design/conduct research on visual-system configurations.
- Compile cost data for visual-system components.
- Assess cost of in-aircraft training.
- Develop improved cost-effectiveness analysis models.
- Assess effectiveness/cost of other ground-based training methods/media.

The primary benefit of this analysis is the quantification of the cost effectiveness of each media mix that is capable of accomplishing the full set of training objectives. In addition, the analytic results will be useful for identifying the components of the visual system that have the greatest impact on training-system cost. When it is not possible to derive accurate estimates of the cost and/or training effectiveness of training-system components that have not yet been designed, this technique can be used to conduct sensitivity analyses to determine the sensitivity of total system cost to variations in the cost and training effectiveness of training-system components.

PRODUCTS OF RESEARCH ON VISUAL SYSTEMS

Figure 3 shows that the results of the research described above will enable Army personnel to formulate detailed design requirements for CIG-based visual systems, specify the requirements for in-aircraft training, and specify requirements for other ground-based training. In addition, the research findings will enable researchers to identify necessary training that cannot be accomplished effectively either in the aircraft or in a simulator equipped with the visual system that is recommended. The unfulfilled training requirements will, in turn, serve to identify requirements for technological innovation.

FIDELITY REQUIREMENTS FOR MOTION SYSTEM

INTRODUCTORY COMMENTS

The Problem

All the flight simulators in the Army's Synthetic Flight Training System (SFTS) inventory are equipped with a platform motion system. Moreover, the design requirements for the AH-64 simulator call for a full six degrees-of-freedom motion platform that is capable of providing cues of motion and vibration associated with both normal conditions and the onset of emergency conditions for the helicopter (Department of the Army, TDR 0027, 1981). Despite the Army's implicit endorsement of motion systems, there are no empirical data that clearly establish the cost effectiveness of platform motion systems for any Army flight simulator. In fact, the results of recent research provide reasons to doubt the cost effectiveness of equipping helicopter flight simulators with platform motion systems.

Numerous studies have been conducted to assess the training benefits of platform motion. An excellent review and critique of the literature on motion systems has been conducted by Semple et al. (1981a). Research conducted since Semple and his colleagues published their work was reviewed prior to preparing this plan. The results of most research conducted to date, especially transfer-of-training research, indicate that little training benefit results from platform motion. Although these findings constitute sufficient justification for questioning the cost effectiveness of platform motion on Army flight simulators, the findings are not sufficiently conclusive to justify the conclusion that the Army should eliminate the use of motion systems on existing and future flight simulators. Listed below are reasons why the current body of research findings does not justify definitive conclusions about the need for motion systems on helicopter flight simulators:

- Nearly all the research on the training benefits of simulator motion has been conducted in fixed-wing aircraft simulators.

- Much of the motion system research has dealt only with skill acquisition in the simulator.
- The lack of evidence that motion systems increase transfer-of-training may be due to unacceptably large lags in the motion systems, problems in the drive algorithms, the use of insensitive performance measures, or some combination of these factors.
- The transfer-of-training research investigated only tasks in which motion feedback is the direct result of pilot control inputs; no tasks were investigated for which simulator motion is a joint function of control inputs and disturbances outside the pilot-aircraft control loop.

So, the problem is this. There is compelling evidence that it may not be cost effective to equip helicopter simulators with platform motion systems. And yet, the case against platform motion is not strong enough to justify a decision to discontinue the use of platform motion systems for existing and future flight simulators. A systematic program of research on motion systems is required to resolve this issue.

Types of Motion Cues

Gundry (1976) has distinguished between two types of motion cues that may have an altogether different effect on skill acquisition in a flight simulator. He defined maneuver motion as the motion that arises within the control loop. Maneuver motion is the direct result of control inputs the pilot introduces to change aircraft attitude, position, or velocity. The feedback provided by maneuver motion is predictable and fully expected by the aviator, so does not necessarily convey new information to the aviator. The second type of motion which Gundry (1976) refers to as disturbance motion results from forces arising outside the control loop and, therefore, is unexpected by the aviator.

Caro (1979) distinguishes between two types of disturbance motion: correlated and uncorrelated disturbance motion. Correlated disturbance motion is motion that results from aircraft equipment malfunctions or failures. Examples of correlated disturbance motion for helicopters are (a) the marked increase in vertical airframe vibration associated with the main rotor being out-of-track, (b) the sudden yaw to the left associated with a partial or complete loss of power, (c) the high frequency airframe vibration associated with an out-of-balance tail rotor, and (d) the violent pitch down, yaw right, and roll left associated with the loss of tail rotor components. When such malfunctions occur, aviators must learn to diagnose correlated motion quickly and to initiate the appropriate control actions promptly if they are to be successful in avoiding a serious accident.

Uncorrelated disturbance motion is motion that is uncorrelated with both aviator control inputs and aircraft malfunctions. Turbulence is the most common source of uncorrelated disturbance motion. But uncorrelated disturbance motion also results from vehicle instability, normal engine vibrations, and normal airframe oscillations. Disturbance motion cues provide information to the aviator that may or may not be redundant with information available in the visual scene.

Hypothesized Training Benefits of Motion

The identification of potential training benefits of motion is a necessary first step in designing research to assess the cost effectiveness of motion systems. Hypothesized benefits are expressed below in the form of questions. The questions posed below represent theoretically possible but not necessarily probable training benefits of motion. Indeed, although the research findings presently available are by no means conclusive, they make it difficult to be optimistic that motion will result in any significant benefit for either skill acquisition or skill sustainment training.

1. Does maneuver motion in a rotary-wing flight simulator enhance learning of the fundamental relationships between control inputs and aircraft responses? As was stated above, most of the research that has been designed and conducted to assess the effects of motion on skill acquisition in the simulator and training transfer from the simulator has dealt mainly or exclusively with maneuver motion. There have been no instances in which maneuver motion has been shown to enhance skill acquisition in or training transfer from a fixed-wing aircraft simulator. The presence of maneuver motion has failed to enhance the transfer of simulator training on (a) aerobatics (Martin & Waag, 1978a), (b) spin, stall, and recovery from unusual attitudes (Ince, Williges, & Roscoe, 1975), (c) air-to-air weapons delivery (Gray & Fuller, 1977), (d) terrain following and avoidance (Parrish, Houck, & Martin, 1977), (e) air-to-air combat (Pohlmann & Reed, 1978), (e) basic contact approaches and landings (Martin & Waag, 1978b), and (f) formation flight (Woodruff, Smith, Fuller, & Weyer, 1976).

Only two studies have been located that were designed to assess the extent to which motion benefits performance in a rotary-wing flight simulator. A study by Fedderson (1962) showed that motion resulted in a small but statistically reliable increase in both rate of skill acquisition in the simulator and transfer-of-training to the aircraft. Fedderson's research, however, was limited to a single flying task: hovering. The second study, conducted recently by Ricard and his associates (Ricard, Parrish, Ashworth, & Wells, 1981), was designed to assess the effects of both platform motion and G-seat motion on experienced aviators' ability to maintain a fixed hover position above a simulated ship. It was found that performance was better with platform motion than with G-seat motion, and that performance with G-seat motion was better than performance with no motion.

The two studies cited above suggest that performance in a rotary-wing flight simulator is affected differently by motion than performance in fixed-wing flight simulators. However, there are at least three explanations for this difference. First, and most relevant to the hypothesis discussed here, it is possible that maneuver motion cues are more beneficial for training in a rotary-wing than in a fixed-wing flight simulator. Second, the difference may result from the presence of disturbance motion stemming from helicopter instability during hover flight. This explanation is compatible with the thesis that disturbance motion cues are important for simulator training, but that maneuver motion cues are not. A third explanation for the differences is that the visual cues available in the fixed-wing simulators were more adequate for the task at hand than were the visual cues in the rotary-wing simulators. Ricard et al. (1981) used a display with a 4[illegible]° horizontal by 36° vertical field-of-view. The absence of a wide field-of-view visual display made the determination of the altitude and fore/aft translation so difficult that it was necessary to add a head-up display (HUD) to supply position information. Fedderson (1962) employed a rudimentary contact analog display that had a field-of-view of 37° by 37°. Fedderson also found it necessary to supplement the basic display with a hovering altimeter. This interpretation is compatible with the thesis that motion cues are not necessary for training if adequate visual cues are available (Cyrus, 1978), and that motion cues may help fill the information gap if the visual cues are inadequate for the flying task at hand (Irish, Grunzke, Gray, & Waters, 1977).

Based upon the research findings available at this time, a best guess is that maneuver motion does not enhance training in rotary-wing flight simulators--especially a flight simulator equipped with a wide field-of-view visual system. However, it will be necessary to conduct further research before it is possible to confidently reject the <u>null</u> hypothesis that maneuver motion in a rotary-wing flight simulator enhances learning of the basic relationships between control inputs and aircraft response. In order to test this hypothesis, it will be necessary to investigate aircraft types and tasks for which aircraft instability is at a minimum. Otherwise, the maneuver motion will be confounded with the disturbance motion that results from aircraft instability.

2. <u>Does the presence of maneuver motion and/or disturbance motion early in training interfere with skill acquisition in the simulator?</u> Anecdotal evidence provided by experienced IPs indicates that the use of platform motion early in training may actually interfere with skill acquisition in the simulator. The IPs report that, early in training, the maneuver motion resulting from unskilled students' control inputs tend to be so severe that the resulting platform motion often is distracting. For instance, pilot induced oscillations severe enough to produce violent platform motion reportedly are encountered frequently when training students in a simulator. No research bearing on this hypothesis has been located.

3. Does the presence of uncorrelated disturbance motion in a rotary-wing simulator increase significantly the rate at which trainees learn to cope with turbulence in the aircraft? Turbulent conditions increase the difficulty of the aircraft control task and increase the information processing load on the operator particularly when flying at low altitude, when operating in confined areas, or both. It seems probable that simulator training under conditions of turbulence would increase trainees' ability to cope with turbulence in the aircraft, but it is by no means certain that the presence of disturbance motion cues would enable trainees to acquire such skills more quickly or to acquire a higher level of such skills than would be possible with visual cues alone. No data to support or refute this hypothesis have been located. An empirical test of this hypothesis will require the measurement of training transfer from the simulator to aircraft flight in turbulent conditions. Because of the requirement to fly in turbulent conditions, such a study would be difficult and hazardous to perform.

4. Does the presence of uncorrelated disturbance motion in a rotary-wing simulator increase significantly aviators' ability to use aircraft motion as an alerting cue? Semple et al. (1981a) report anecdotal evidence that motion cueing may be necessary for simulator training on tasks and conditions that require aviators to maintain control of the aircraft while performing other tasks. The thesis is: when the aviator is attending to tasks other than aircraft control, motion cues alert him to the need to attend to the control function and to make corrective control inputs. This alerting function of motion is presumed to be especially important when aviators must maintain aircraft control while performing tasks that require them to view cockpit displays and controls. It is conceivable that the alerting function of motion may be important for simulator training of both contact and instrument flight.

5. Does training in a simulator equipped with a motion system increase aviators' ability to diagnose and respond to aircraft failures and malfunctions that are signalled by unusual airframe motion? Caro (1979), among others, has suggested that a simulator capable of generating correlated disturbance motion can be used to train aviators to correctly diagnose and respond to the types of aircraft failures and malfunctions that are signalled by sudden airframe movements, the onset of airframe vibration, or both. The underlying assumption is that aviators trained to use motion cues can diagnose failures more accurately and can initiate appropriate control inputs more quickly than would be possible with visual cues alone.

Although the potential payoff of training on emergency maneuvers is great, it will be difficult to make an objective assessment of the benefits of such training. One source of difficulty stems from problems associated with measuring training transfer to the aircraft. The measurement of training transfer requires that aviators' responses to selected malfunctions be measured in the aircraft. Here lies the problem. Some types of malfunctions simply cannot be simulated in the

aircraft by temporarily disabling an aircraft component; other malfunctions can be simulated in the aircraft by temporarily disabling an aircraft component, but it is excessively hazardous to do so. A second source of difficulty stems from problems in assessing the benefits that result from effective training on emergency maneuvers. Ultimately, the only benefits that result from such training are reductions in the incidence and consequences of accidents. Because accident frequency is so low, several years would be required to accumulate sufficient accident data to assess the impact of emergency procedures training on accident frequency and severity; this is true even if the training on emergency procedures were conducted Armywide.

6. Does training in a simulator equipped with a platform motion system effect the likelihood that aviators will become disoriented during contact and/or instrument flight in the aircraft? All arguments that favor the use of motion systems are based on the fundamental belief that aircraft motion conveys information that enables experienced aviators to perform better on some tasks than would be possible by attending only to visual cues. In a word, the argument is that motion in the simulator teaches aviators to better use motion cues in the aircraft. This argument seems to be in direct conflict with the practice of teaching all Army aviator trainees that motion cues may lead to serious spatial disorientation during flight (see TC 1-20). The implication of this training is that aviators must learn to disregard motion cues, especially when visual cues are degraded by darkness or atmospheric attenuation. Because of aviators' susceptibility to motion illusions (leans, Coriolis illusions, and proprioceptive illusions[12]), one cannot discount the possibility that training aviators to take full advantage of the information conveyed by motion cues in the simulator may increase the incidence of disorientation in flight. On the other hand, one cannot discount the possibility that simulators designed to teach aviators how and when to use motion cues may decrease aviators' susceptibility to disorientation induced by motion illusions.

7. To what extent can the cues provided by platform motion be produced by force cueing devices? This question is relevant only if platform motion is found to enhance training transfer to the aircraft. Ricard et al. (1981) found that skill acquisition in the aircraft is enhanced by G-seat motion, but not to the extent that skill acquisition is enhanced by platform motion. Although this research was limited to a single task--hovering--and utilized a display with a relatively narrow field-of-view, the findings nevertheless support the hypothesis that force cueing devices convey some useful information to the aviator. Additional research is needed to assess the relative benefits of platform motion and force cueing for a wider range of tasks and a wider range of force cueing devices.

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[12]See TC 1-20 for the definition of leans, Coriolis illusions, and proprioceptive illusions.

8. Is simulator sickness influenced by maneuver motion, disturbance motion, or both? Heretofore, it has been assumed that simulator sickness occurs rarely and that individuals who experience simulator sickness quickly adapt to the simulator. The results of recent research indicate that motion sickness is more prevalent and more severe than has previously been supposed. Incidents of simulator sickness have been reported recently in fighter aircraft simulators (McGuiness, Bouwman, & Forbes, 1981), patrol aircraft simulators (Crosby & Kennedy, 1982), and helicopter simulators (Frank & Crosby, 1982). Moreover, there have been reports of simulator sickness in both fixed-base and moving-base simulators (Frank, Kellogg, Kennedy, & McCauley, 1983). Symptoms of motion sickness have occurred not only during the simulator flight but, in some cases, have lasted several hours past exposure. Some aircrews have reported the onset of symptoms as much as eight hours after terminating the simulator flight (Kellogg, Castore, & Coward, 1980).

Although a great deal is known about motion sickness, current knowledge is insufficient to predict the influence of platform motion on the incidence and severity of simulator motion. Further research is required to determine whether the presence of platform motion effects motion sickness and, if so, to determine the relationship between the characteristics of motion and motion sickness. This research must address maneuver motion and disturbance motion separately and in combination.

PROPOSED RESEARCH PLAN: MOTION-SYSTEM FIDELITY

The proposed research plan is illustrated schematically in Figure 4. It should be noted that the research plan contains three decision points at which the findings of the previous research tasks dictate what tasks are to be accomplished subsequently. Initially, a series of studies will be designed and conducted to assess the effect of motion on skill acquisition in the simulator. If no evidence is found that motion enhances skill acquisition in the simulator, the research will be terminated and a recommendation will be made to discontinue the procurement of motion systems for rotary-wing simulators.

The second decision point occurs after the completion of a series of transfer-of-training studies. If the research findings show that transfer-of-training is enhanced by motion, the cost effectiveness of candidate motion systems will be assessed; otherwise, the research will be terminated at this point with the conclusion that motion systems cannot be cost effective.

The final decision point occurs after cost-effectiveness analyses have been completed. If none of the candidate motion systems prove cost effective, there obviously is no need to proceed further. However, if the cost-effectiveness data show one or more motion systems to be cost effective, research on motion sickness will be reviewed (or conducted, if necessary) and design requirements for the most cost-effective system(s) will be developed.

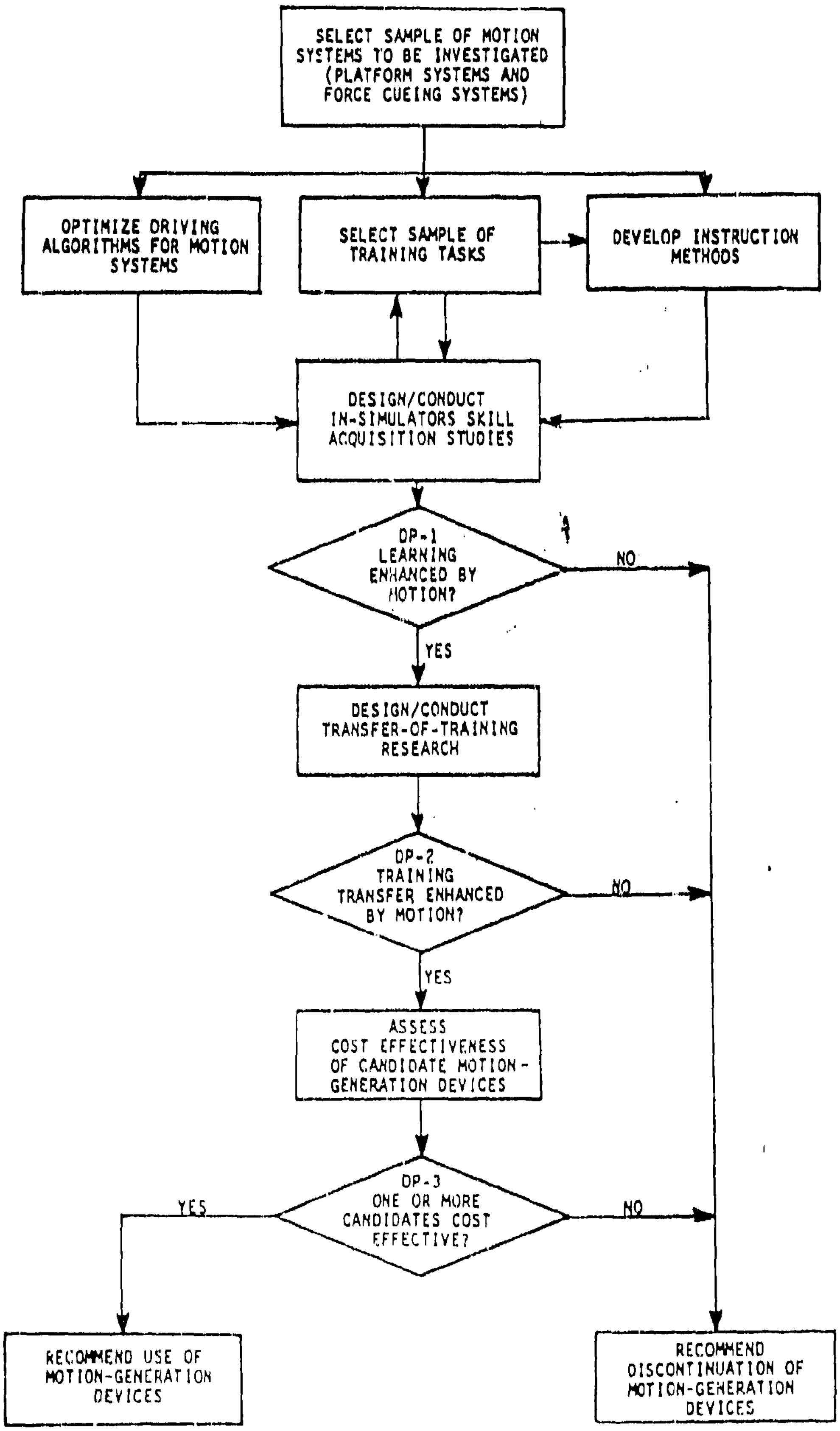

Figure 4. Task-flow diagram for research plan on motion systems.

The research was designed in this manner to avoid the high cost of conducting transfer-of-training research if there is no necessity to do so. Obviously, the most critical assumption underlying this research plan is that a lack of evidence that motion enhances skill acquisition in the simulator is sufficient justification to conclude that motion will not enhance training transfer from the simulator to the aircraft. Although this assumption cannot be questioned on logical grounds, there is a risk that, in practice, some form of useful learning could occur in the simulator that is not reflected in the performance measures that are employed. Every attempt must be made to minimize this risk through the careful consideration and selection of performance measures and, perhaps, through the conduct of preliminary research to validate the set of performance measures that are adopted.

Each of the proposed research tasks is described in the following paragraphs.

Select Sample of Motion Systems

Ideally, the in-simulator research would be conducted to assess the benefits of both platform motion systems and the full range of force cueing devices that might replace or augment platform motion systems. Many of the existing force cueing devices evolved as a result of attempts to simulate G-force cues present in high performance, fixed-wing aircraft. Examples of such devices include G-suits, G-seats, helmet-loaders, arm-loaders, and visual grayout/blackout capabilities. Since G-forces exceeding one-G are seldom experienced in helicopters, the use of force cueing devices for the sole purpose of G-force cueing makes little sense for helicopter simulation. Of the force cueing devices that have been developed, only the seat shaker, the G-seat, and the stick shaker promise to provide cues that may replace or augment the cues generated by a platform motion system. The G-seat is the only one of the force cueing devices that is capable of producing cues to high amplitude, low frequency motion; so, the G-seat is the only force cueing device that has significant potential for replacing platform motion cues. Stick shakers and seat shakers have the potential for simulating cues associated with low amplitude motion resulting from airframe vibration. For the most part, these high frequency, low amplitude cues are beyond the capability of platform motion systems and G-seats--at least as they are presently configured.

Based upon the information in hand, it appears that the in-simulator research should investigate the benefits of platform motion and at least three force cueing devices: G-seat, stick shaker, and seat shaker.

Optimize Driving Algorithms

Non-optimal algorithms for driving the motion systems investigated could invalidate the motion system research, so it is essential that effort be expended at the outset to ensure that the driving algorithms are as effective as they can be made. Algorithms must be evaluated in terms of (a) the delay between control inputs and the onset of motion, (b) the synchronization of visual and motion system movements, and (c) the extent to which the motion generated by the algorithm elicits the appropriate perceptions of motion.

Research on fixed-wing aircraft simulators has shown that excessive delays in the platform motion system and excessive asychronization of the platform motion system and the visual system may degrade performance in the simulator and may cause disorientation and simulator sickness (Ricard & Puig, 1977; Puig, Harris, & Ricard, 1978). However, considerable uncertainty exists about what is "excessive." Ricard and Puig (1977) concluded that simulation system delays (motion and visual) should not exceed 125 milliseconds, but Riley and Miller (1978) report that delays of as much as 250 milliseconds can be tolerated in some instances. Apparently, these differences stem wholly or in part from differences in the flying tasks investigated. Semple et al. (1981a) recommended that the delay between visual and motion cues should not exceed 50 milliseconds for highly dynamic maneuvering and 150 milliseconds for less dynamic maneuvering. However, this recommendation was aimed specifically at fixed-wing aircraft maneuvering and, furthermore, was based upon "informed opinion" rather than empirical data.

The research data on maximum tolerable motion delays and maximum tolerable visual/motion asychronization are sketchy and the generalizability of the data to helicopter simulators is questionable. Moreover, it is not known whether the conclusions drawn from research on platform motion are valid for force cueing devices. Because of the lack of relevant data, it may be necessary to conduct preliminary research to ensure that the shortest delays and the greatest visual/motion synchronization obtainable with the research equipment available are near optimal. Stated differently, it is essential that the in-simulator research to assess skill acquisition on various tasks not be invalidated by a motion driving algorithm that generates excessively long lags and excessive visual/motion asychronization.

The necessary research would require that skill acquisition be measured for the shortest delay achievable and for several progressively longer delays. It could be concluded that the shortest delay achievable is near optimal if the skill acquisition rate reaches an asymptotic level at a delay longer than the shortest delay achievable with the equipment. For instance, suppose the shortest delay achievable is 50 milliseconds and that skill acquisition rate is investigated for 50 milliseconds, 100 milliseconds, 150 milliseconds, and 200 milliseconds. If skill acquisition rate increases as delay decreases to an asymptotic level at 100 milliseconds, it can be concluded that use of a 50 millisecond delay is near optimal and that valid research on motion can be

conducted with an algorithm that generates a delay of 50 milliseconds. Preliminary research should be conducted to assess delays (both the delay between control input and motion onset and the delay between visual and non-visual motion) for platform motion and each force cueing device selected for study.

No empirical research has been located that assesses that extent to which motion driving algorithms developed for helicopter simulators, in fact, generate motions that elicit the appropriate perceptions. Perceptions are appropriate if the motion enables the individual experiencing the simulator motion to make valid inferences about the motion of the simulated aircraft. Heretofore, algorithms for platform motion have been "tweeked" until experienced aviators judge that the "feel" is about right. However, anecdotal evidence from experienced Army aviators indicate that aviators seldom agrae on what "feels" about right. No easy solution to this problem can be offered at this time. Research to optimize driving algorithms with respect to the perceptions they generate probably will involve both engineering and psychophysical studies. Engineering studies are required to ensure that the driving algorithm is producing the desired amplitudes, accelerations, and frequencies. Psychophysical studies are required to ensure that the physical motion is generating the appropriate perceptions.

Select Sample of Training Tasks

As shown in Figure 4, the selection of training tasks must be accomplished concurrently with the design of specific in-simulator studies. The objective is to select a sample of training tasks that, together, cover (a) the full range of tasks for which training may be facilitated by the presence of motion cues, and (b) the full range of motion types encountered in helicopters.

Develop Instructional Methods

Ineffective instructional methods can easily mask the effects of any independent variable investigated in a skill acquisition study. As a consequence, it is essential that instructional methods be developed, pretested, and refined prior to the initiation of the in-simulator research. Specific instructional procedures for each training task investigated must be developed for both the experimental group(s) and control group(s).

Design/Conduct In-Simulator Studies

Skill acquisition is the main dependent variable for all of the in-simulator research. Both skill acquisition rate and asymptotic skill level are of interest. Incidences of aviator disorientation and simulator sickness should be recorded, but research specifically designed to

assess the effects of motion on aviator disorientation and simulator sickness is considered beyond the scope of the present study. The independent variables that must be investigated include but are not necessarily limited to the following:

- type of motion (maneuver motion, correlated disturbance motion, and uncorrelated disturbance motion),
- motion-generation method (platform motion, G-seat, seat shaker, stick shaker),
- aircraft stability (varied by selecting tasks for which aircraft stability differs),
- stability augmentation (varied by systematically disabling parameters of the stability augmentation system),
- stage of skill acquisition at which motion cues are first introduced,
- aviator task-loading/time-sharing requirements, and
- type of aircraft malfunction.

Motion is the primary independent variable; the other independent variables listed above are secondary in the sense that they are variables that may influence the magnitude of motion's effect on skill acquisition.

It will not be possible to formulate specific experimental designs until final decisions are made about the hypotheses to be tested. The hypotheses discussed in the introduction of this subsection are illustrative but should not be considered comprehensive. Although experimental designs cannot be specified at this time, the development of suitable designs for this research is <u>not</u> viewed as a difficult task. The main consideration in formulating experimental designs is to ensure that the design includes a (no-motion) control group against which performance of each experimental group can be compared.

It is expected that several pilot studies will be required to develop suitable procedures for this research. In principal, the general procedure is simple and straightforward: train all members of the experimental (motion) groups and control (no-motion) group(s) to an asymptotic level on selected flying tasks. One problem in implementing this procedure is that of defining when performance reaches an asymptotic level. Although this problem is by no means unusual, preliminary research will be necessary to get a general idea of the rate at which skill on each task is acquired and to develop specific criteria for judging when performance on successive practice trials has become sufficiently stable to be considered asymptotic.

A second procedural problem is that of ensuring that subjects have the prerequisite skills needed to learn a given flying task effectively. Subjects with no prior flying experience whatsoever would make little progress in learning a difficult task such as an autorotation. It is

certain that some amount of preliminary training will be necessary to accurately assess the effect of motion on the learning of the more difficult flying tasks. One solution to this problem, and possibly the best one, is to develop a comprehensive program of instruction that commences with the easiest flying tasks and progresses to the more difficult tasks, training each task to an asymptotic level before proceeding to the next task. Assessing the effects of motion on essentially all the tasks that can be trained in the simulator would be time-consuming, but would provide the data needed to assess both (a) the effects of motion on individual tasks and (b) the accumulated effects of motion throughout the program of instruction.

The third important procedural problem is that of defining effective performance measures for each flying task investigated. Obviously, it is essential that the performance measures provide a reliable and a sensitive index of the rate and level of skill acquisition. A less obvious requirement is for performance measures that have value in diagnosing differences in skill acquisition.

Decision Point One

Once the in-simulator research has been completed, it will be necessary to decide whether further research should be conducted. Specifically, the composite findings of the in-simulator research must be assessed to determine whether the beneficial effect of motion on skill acquisition is sufficiently large to justify the design and conduct of transfer-of-training research. Such an assessment must be made for the platform motion system, each of the four cueing devices, and each combination of motion-generation devices that is investigated.

A decision to terminate the research at this point will be a simple matter if no evidence is found that motion enhances skill acquisition in the simulator or, conversely, the evidence indicates that motion benefits in-simulator skill acquisition significantly and uniformly--across tasks and motion-generation devices. The decision will be a difficult one to make in the more likely event that the findings are mixed: motion from some of the motion-generation devices is found to benefit skill acquisition on some flying tasks. In the event of mixed findings, there is no alternative to the use of informed judgment in deciding whether or not to proceed with the transfer-of-training research. It is recommended that the decision to continue or terminate the research on motion at this point be made by a team composed of a multi-disciplinary team of subject matter experts after a comprehensive review and discussion of the research findings.

Design/Conduct Transfer-of-Training Research

The objective of the transfer-of-training research is not merely to determine whether the benefits of simulator motion transfer to the

aircraft. Rather, the objective is to collect the data needed to determine whether the increase in training transfer attributable to simulator motion is great enough to offset the cost of providing motion cues during simulator training. A separate transfer-of-training study must be conducted for each motion-generation device, or combination of devices, found to enhance in-simulator training to a significant degree.

A fully comprehensive cost-effectiveness assessment of motion-generation devices requires that transfer-of-training be measured for IERW training, transition training, and continuation training. Although all IERW training is presently conducted in an aircraft, plans have been made to conduct research to determine the amount of IERW training that can be accomplished in a flight simulator. If simulator training proves to be effective, the transfer-of-training studies proposed here definitely should include IERW training; otherwise, the studies should be limited to transition and continuation training. Because of the difficulties associated with assessing the effectiveness of continuation training, it is recommended that studies first be performed to assess the extent to which motion benefits the simulator training of IERW and transition-training tasks. It is possible that the results of these studies will be adequate to make a decision concerning the cost effectiveness of some or all of the motion-generation devices for use in continuation training.

The traditional paradigm for measuring the transfer of simulator training consists of (a) training a control group to criterion exclusively in the aircraft, and (b) training an experimental group first in the simulator and then to criterion in the aircraft. The paradigm appropriate for measuring the effect of motion on the transfer of simulator training differs from the traditional paradigm only in terms of the control group; the control group receives simulator training with no motion and then is trained to criterion in the aircraft. The use of a control group trained to criterion exclusively in the aircraft is considered essential only if the effectiveness of the simulator training has not been validated.

A key issue in designing the transfer-of-training studies is the selection of the tasks that are to be trained in the simulator. The tasks of interest are the ones for which skill acquisition was enhanced by the presence of motion. However, because of the interdependencies among flying tasks, it is unlikely that the simulator training can be limited to tasks that are found to benefit from simulator motion. As was stated earlier, effective training on some flying tasks is not possible until the trainee has acquired certain prerequisite skills. As a consequence, the simulator training must include both the tasks that are known to benefit from the presence of motion and tasks that enable subjects to acquire prerequisite skills. Preliminary research definitely will be required to identify prerequisite skills and the tasks that must be trained in the simulator to ensure that the subjects possess the prerequisite skills.

The design of research to assess the extent to which motion increases the utility of flight simulators for accomplishing continuation training is complicated by the lack of data on skill decay. The benefits of using a flight simulator for continuation training cannot be measured unless the relevant flying skills are permitted to decay. And yet, no data are available to use in estimating performance degradation on various flying tasks as a function of variables such as aviator experience (total flying hours) and the amount of flying an aviator has experienced since his last successful proficiency checkride. Until such data are available, it will not be possible to design efficient and meaningful research to determine the impact of motion on continuation training and flight simulators.

A final important research design issue concerns the assessment of motion's effect on the simulator training of responses to certain aircraft malfunctions. Responses to some malfunctions cannot be practiced or assessed in the aircraft--either because the malfunction cannot be simulated in the aircraft or because it is too dangerous to do so. Obviously, it is not possible to measure training transfer from the simulator to the aircraft if it is not possible to measure performance in the aircraft. No solution to this problem is apparent at this time.

Decision Point Two

If the research findings indicate that training transfer is increased by a motion-generation device, a decision will be made to proceed with a detailed analysis to assess the cost effectiveness of that device. It will be recommended that the Army discontinue procurement/use of motion-generation devices found to have a negligible effect on training transfer.

Assess Cost Effectiveness of Candidate Motion-Generation Devices

The objective of this task is to determine if the savings in training costs realized from the use of motion during simulator training is great enough to offset the life-cycle costs of the motion-generation device. Training-cost savings will be estimated for each motion-generation device that is found to enhance training transfer. In concept, calculating the training-cost savings attributable to motion is accomplished merely by subtracting the total costs of training with motion from the total costs of training without motion. To estimate total training costs, it is necessary to compile accurate direct and indirect cost data for both the simulator and the aircraft training.

The methods for calculating training costs are discussed in detail elsewhere (DOD, 1973; Orlanski & String, 1977; Marcus et al., 1980; Mayer, 1981). However, one problem that is unique to this research mus. be acknowledged. There are certain indirect costs associated with platform motion that are difficult to estimate. It is difficult to

estimate the added cost of producing visual systems that are compact enough to be mounted on a motion platform and yet rugged enough to tolerate the physical stress of movement in six degrees of freedom. It also is difficult to estimate the added costs of building, heating/cooling, and maintaining a structure that is much larger than would be required to house a simulator without a platform motion system. Clearly, careful study will be required to derive accurate estimates of such costs.

Decision Point Three

The effort will be terminated at this point if the cost-effectiveness analysis shows that negligible training-cost savings are realized from the use of motion during simulator training.

Formulate Recommendations

If the training-cost savings are of practical importance, it will be recommended that the cost-effective motion device(s) be employed on present and future helicopter simulators. The composite research findings will be used to formulate functional design requirements for the motion-generation device(s) recommended for use.

HANDLING-QUALITIES FIDELITY REQUIREMENTS

Handling-qualities fidelity is the extent to which the simulated aircraft responds to control inputs and environmental forces in the same manner as the aircraft being simulated. Ultimately, handling qualities must be defined in behavioral rather than engineering terms. Measurable differences between the handling qualities of the simulator and the aircraft are significant only to the extent that they influence user acceptance and training effectiveness. Differences that are discriminable by experienced aviators may influence user acceptance but may or may not influence training effectiveness. Conversely, it is conceivable that differences that cannot consciously be discriminated by experienced aviators could adversely affect training effectiveness. Hence, discriminability of differences is important to the extent that user acceptance is affected. Otherwise, training effectiveness is the main criterion that must be considered in establishing requirements for handling-qualities fidelity.

The fidelity of a simulator's handling qualities is determined by the characteristics of three math models: the control system model, the environment model, and the aerodynamic model. A great deal of time and resources have been expended by the Army and Army contractors in attempts to increase the validity and efficiency of the models used for rotorcraft simulation. Much of this work, however, has been motivated by the need to develop effective design simulators rather than the need

to develop effective training simulators. It is probable that the highly sophisticated models developed to aid in the design of advanced rotorcraft may be far more complex than are needed for training simulators (R. K. Heffley, Manudyne Systems, Inc., personal communication, 1985).

Consideration of the state of knowledge on handling-qualities fidelity has led to the conclusion that two related lines of research are required. The objective of one line of research--principally but not exclusively behavioral research--is to compile data with which to plot the relationship between handling-qualities fidelity level and training effectiveness. The objective of the second line of research--principally engineering research--is to develop more cost-effective ways to achieve adequate levels of handling-qualities fidelity. The second line of research must address the design of the math models used in training simulators and the hardware and software used to implement the math models. Given the rapid growth in related technology, it is highly probable that new techniques and/or equipment could effect a drastic reduction in the cost of producing a high level of handling-qualities fidelity. Cost reduction, in turn, has an important influence on the level of handling-qualities fidelity that is most cost effective.

The remainder of this subsection focuses on the first line of research mentioned above. There are two main issues that must be dealt with before it will be possible to develop a detailed design of research to define handling-qualities fidelity requirements. These issues are discussed below.

QUANTIFYING LEVEL OF HANDLING-QUALITIES FIDELITY

In order to define the optimal level of fidelity for any simulator-design parameter, it is necessary to measure training effectiveness as the fidelity of the parameter is varied systematically from some relatively low level to some relatively high level. At present, a study of handling qualities is complicated by the fact that there are no acceptable methods for quantifying the similarity between the handling qualities of the simulator and the handling qualities of the simulated aircraft. Previous attempts to use experienced aviators to subjectively assess the handling qualities of simulators have not proved highly successful.

Efforts are being made to decrease the subjectivity of handling-qualities assessment by using more flight-test data and by using specially trained engineering test pilots (Woomer & Carico, 1977). However, the value of even specially trained engineering test pilots for quantifying handling-qualities fidelity must be considered questionable because of the rapidity with which aviators accommodate to the handling qualities of a particular simulator. In this regard, Semple and his colleagues state:

> Evidence has been cited... that pilots will accommodate to air training device cues and responses after as short a period in the air training device as 30 minutes (Eddowes, 1977; Harris, 1977; Woomer & Carico, 1977; and Rust, 1975). Beyond this time, even... evaluation by specially trained acceptance test pilots can be inaccurate (Semple et al., 1981a, p. 108).

The best way to proceed in resolving this important problem is not apparent at this time. Two divergent approaches should be investigated. One approach would begin with an analytical study to define the behavioral dimensions of handling qualities. That is, given a known control input or environmental disturbance, what is it that the aviator perceives that differentiates the handling qualities of one aircraft from the handling qualities of another? Once the fundamental dimensions have been hypothesized, it would be necessary to develop math models that would enable the researcher to vary the value of each dimension in a systematic way, and to conduct studies to "scale" each dimension. A multidimensional scaling technique probably would be most appropriate for this purpose.

A second approach, quite different from the first, is to operationally define handling-qualities fidelity in terms of the characteristics of the math models used to drive the flight simulator. The most relevant characteristics are those that have the most significant influence on the cost of implementing the math models. The concept of this approach is to commence with a very simple model and to assess the impact on handling qualities as the complexity of the model is systematically increased. The feasibility of this approach is dependent on the development of an effective way to measure the similarity between the handling qualities of the simulator and the aircraft as the models' characteristics are varied. As has been stated above, the use of subjective judgments of aviators for this purpose is not promising. Hence, the use of this approach is probably contingent on the development of an objective method for measuring both the simulator's and the aircraft's response to known control inputs and environmental disturbances. Assuming this goal can be achieved, the interim product would be a set of data that quantify the relationship between math model complexity and measured differences in handling qualities. Behavioral research then would be required to determine the relationship between training effectiveness and the measured differences in the handling qualities of the simulator and aircraft.

VARIABLE HANDLING-QUALITIES FIDELITY REQUIREMENTS

Research to define the most cost-effective level of handling-qualities fidelity is complicated greatly by the high likelihood that the minimum acceptable fidelity level differs for different training applications. Based on a thorough review of the literature and information gained from visits to simulator training facilities, Semple sets forth the supposition that:

> The requirement for (handling-qualities) fidelity is diminished for trained tasks which are in the middle of the performance envelope of the pilot and aircraft system. As the trained tasks increase in difficulty and approach the performance limits of the pilot and aircraft combination, the requirement for high levels of (handling-qualities) fidelity increased accordingly (Semple et al., 1981a, p. 116).

If Semple's supposition is correct, it follows that there is no single level of handling-qualities fidelity that is ideal for training all tasks and all aviators. Furthermore, it follows that handling-qualities fidelity requirements vary as a function of the proficiency level desired on the first aircraft following simulator training (first-flight proficiency level). Semple's rationale clearly is sufficiently compelling to justify further research on this potentially important issue. Specifically, aviator skill level, task difficulty, and "first-flight" proficiency level should be treated as independent variables in the research to define handling-qualities fidelity requirements. Specific research questions include but are necessarily limited to those discussed below.

- To what extent do handling-qualities fidelity requirements vary as a function of stage of training?
- At each stage of training, to what extent can low levels of handling-qualities fidelity be compensated for by experienced instructor pilots?
- Does a high level of handling-qualities fidelity inhibit learning in the beginning student?
- To what extent do handling-qualities fidelity requirements differ for skill acquisition training and skill sustainment training?
- Given that handling-qualities fidelity requirements vary as a function of task difficulty, is it cost effective to establish handling qualities for the worst case condition, i.e., the most difficult task and the least skilled aviator encountered at the training stage for which the simulator is to be used?
- If handling-qualities fidelity requirements differ for different training stages, is it technically feasible and cost effective to make handling qualities easily adjustable so that the same simulator can be used to train students at different stages of training? If handling qualities were changed in different training stages, what would be the effect on training transfer as students transition from one training stage to another?
- Given that handling-qualities fidelity requirements vary as a function of "first-flight" proficiency level desired, what level of fidelity is required to achieve near perfect first-flight execution of tasks that are dangerous to practice in the aircraft, e.g., emergency touchdown procedures, pinnacle landings under heavy wind conditions?

- Can handling-qualities fidelity requirements be accurately predicted from a study of the consideration of the skill components of a task, e.g., procedural vs. psychomotor, ballistic vs. continuous-adjustment control inputs?

FIDELITY REQUIREMENTS FOR COCKPIT DISPLAYS/CONTROLS

With few exceptions, the external appearance of the displays and controls in contemporary Army flight simulators is the same as those found in the aircraft. Typically, off-the-shelf displays and controls used in the aircraft itself are purchased and modified as necessary by the simulator manufacturer. The modifications required to adapt the off-the-shelf instruments for simulator use are often major and, therefore, costly. Some off-the-shelf displays, for instance, require altogether new internal drive mechanisms. Simulator manufacturers are also careful to reproduce realistic display and control response characteristics (e.g., altimeter response lag and cyclic control loading) and to configure the simulator displays and controls in the same way that they are configured in the aircraft. In short, the Army's flight simulator cockpits have a very high level of fidelity.

There has been no systematic research conducted to define alternatives to the high-fidelity cockpit instruments found in most military flight simulators or to assess the training effectiveness of lower fidelity alternatives. Such research is clearly needed.

A study of fidelity requirements for cockpit displays and controls should commence with a technology survey to identify the full range of alternatives to the displays and controls presently being used. Certainly, consideration should be given to the utility of dynamic, computer-generated images of conventional dials, gauges, and status displays. Consideration should also be given to the utility of touch-sensitive panels as replacements for conventional switches, thumbwheels, and knobs. Once the alternatives have been identified, a preliminary cost analysis should be conducted to identify the alternatives that promise to be less costly than the conventional display/control that would be replaced. Further effort would be justified only if the cost of one or more of the alternatives is found to be clearly less than the cost of the conventional counterpart.

If less costly alternatives are found, as is almost certain to be the case, the next step would be the conduct of empirical research to assess the training effectiveness of each alternative. If the training effectiveness of the alternative(s) is found to equal or exceed that for its conventional counterpart, the issue is resolved: it must be concluded that the alternative is more cost effective. However, if both the cost and the training effectiveness of the alternative is less, a cost-effectiveness analysis would be required to determine whether the cost savings are large enough to offset the loss in training effectiveness. Although difficult to quantify, user acceptance should not be

ignored in drawing final conclusions about the suitability of alternative displays/controls.

It would be premature to propose a research design to assess fidelity requirements for simulator displays/controls until alternatives have been identified and their cost estimated. However, it seems unlikely that the research would be particularly difficult to design.

REQUIREMENTS FOR INSTRUCTIONAL SUPPORT FEATURES

Hughes (1979) defines ISFs as simulator hardware and software that allow the instructor/operator to manipulate, supplement and otherwise control the learning experience of the student to maximize the rate and level of skill acquisition. Examples of ISFs available on existing Army helicopter simulators include Problem Freeze, Record and Playback, Automated Checkride, Instructor/Operator Console Displays, and Automated Performance Measurement. Although all simulators in the SFTS are equipped with some combination of ISFs, little is presently known about how ISFs should be used or the extent to which properly used ISFs increase training effectiveness. The research described in this subsection of the research plan has been designed to resolve uncertainties about the proper use and training effectiveness of ISFs. Specifically, the objectives are:

- to define potentially effective ISFs,
- to define the optimal use of potentially effective ISFs, and
- to assess empirically the cost effectiveness of ISFs, individually and collectively.

INTRODUCTORY COMMENTS

The following paragraphs briefly describe several observations and conclusions, drawn from a review of the literature on ISF design and use, that have had an important impact on the proposed research.

ISF Contribution to Simulator Cost and Training Effectiveness

Empirical evaluation of the utility of ISFs has not been conducted to provide input into the concept development and design phases of the simulator hardware and software acquisition process. Rather, it appears that ISFs have been incorporated into existing flight simulators based solely on logical and analytical consideration of their potential utility.

The Cost and Training Effectiveness Analyses (CTEAs) that are conducted on new flight simulators are designed to determine the training effectiveness of the simulator relative to the training effectiveness of the target aircraft. The statistical and methodological

requirements of the CTEA are such that aircraft training and simulator training are conducted in as similar a fashion as possible. Thus, the CTEA process is not designed to yield information about the cost and training effectiveness of particular ISFs or about their applications. Moreover, the Operational Tests I and II conducted by the Army have provided no information about ISF's contribution to the overall cost and training effectiveness of the device.

ISF Training Effectiveness

Only a few experimental studies have been conducted to assess the training effectiveness of ISFs. All the studies located during the literature review were conducted either by the Air Force Human Resources Laboratory (AFHRL) or the Naval Training Equipment Center (NTEC). The AFHRL research has been conducted with the Air Force's Advanced Simulator for Pilot Training (ASPT). The NTEC research has been conducted with the Navy's Visual Technology Research Simulator (VTRS). Both of these flight simulators are for fixed-wing aircraft, which have very different missions than those of the Army's rotary-wing cargo, utility, observation, and attack aircraft. The generality of findings from the studies discussed below to ISF use on the Army's SFTS is not now known.

Hughes, Hannan, and Jones (1979) compared the benefits of instructional use of the Automated Demonstration ISF and the Record and Replay ISF with the benefit realized from performing one additional training iteration of a cloverleaf maneuver. While use of the Record and Replay ISF was found to be superior to the use of the Automated Demonstration, the performance of a single extra training trial in the simulator produced better pilot performance than the use of either ISF. In this instance, this particular instructional use of the ISFs made no significant contribution to the training effectiveness of the ASPT for that maneuver.

In another relevant investigation, Hughes, Lintern, Wightman, Brooks, and Singleton (1982) studied two applications of the Problem Freeze ISF. In the "Freeze/Reset" application, the simulator was placed on Freeze when an error was detected; once the error was explained, the simulated aircraft was placed in the appropriate position, and the student continued the task from the "corrected" position. In the other application called "Freeze/Flyout," the actions during the Freeze were the same as during the Freeze/Reset condition, except the student continued the task from the exact point at which the simulator was frozen. Finally, in a third condition, students learned the task without the use of the Freeze ISF.

The results of this study indicated no differences in performance between the two ISF applications and the condition in which the Freeze ISF was not used. The pilots reported that they were more motivated by "trying to avoid the 'Freeze' than by trying to fly the task correctly."

Pilots also reported that trying to regain control of the simulator following a "Freeze" significantly increased the difficulty of the task. Again, empirical testing of a particular instructional use of ISFs revealed no significant advantages.

One study was found that demonstrated a significant training benefit attributable to an ISF application. Bailey, Hughes, and Jones (1980) studied an instructional use of the Initial Conditions (IC) set with a dive-bombing task in the ASPT. These investigators divided the entire task into seven segments: crosswind, downwind, base leg, roll in, final dive, and release point. Using a procedure called "backward chaining," the student was placed at the end of final dive with the IC set and then learned the release point segment to criterion. Then the next-to-last segment--the final dive--was added to the release point segment and the student learned the combined segments to criterion. This "chaining" of one task segment to an earlier one was continued, using the IC set at each phase, until the student learned to perform the task to criterion in its entirety.

The performance of subjects in this backward chaining condition was then compared to the performance of subjects who learned the task in the traditional manner in the simulator. The results showed a statistically significant and practical advantage to the use of the IC set ISF with the backward chaining procedure. The subjects performed better and reached criterion faster than the traditionally trained subjects. This use of the IC set ISF produced better performance while also producing a savings in training time.

Instructor/Operator Training

While a programmatic research effort will identify cost-effective applications of ISFs, this information will be of little benefit without a cadre of well-trained simulator instructor/operators. Review of the relevant literature reveals a consensus that simulator instructor/operators are insufficiently trained for their complex and critical role. In addition, as a research issue, Army simulator instructor/operator training has received no attention.

Hammell (in Ricard, Crosby, & Lambert, 1982) provides clear evidence of the criticality of the simulator instructor/operator. In a study of the training effectiveness of several different levels of fidelity in a shiphandling/shipbridge simulator, the effects attributable to different instructors were found to be several times larger than the effects attributable to fidelity levels. The magnitude of instructor differences is surprising in that the fidelity levels studied were specifically selected for their presumed impact on training effectiveness.

Charles, Willard, and Healy (1976) and Gray et al. (1981) conducted surveys of simulator instructor/operator training in the Navy,

and the Air Force, respectively. The results of these surveys indicate that some ISFs are frequently not utilized at all, while other ISFs are used primarily for management rather than instructional purposes. Similarly, reports by Caro (1977a) and Semple, Cotton, and Sullivan (1981b) indicate that simulator instructor/operators are often unaware of the operation and capabilities of the ISFs in the simulators with which they regularly train students. While the generality of these findings to Army SFTS instructor/operators is unknown, the need to examine and, if necessary, to augment their training seems apparent.

PROPOSED RESEARCH PLAN: INSTRUCTIONAL SUPPORT FEATURES

The review of available literature on ISF utilization indicates that additional, operationally oriented research is needed to determine the optimal uses of ISFs in simulation training. This section describes a four-phase research program that has the terminal objective of providing task-level empirical data that are needed to identify the most cost-effective application of ISFs in the Army's SFTS.

Figure 5 is a flow diagram of the tasks that must be accomplished to meet the terminal objective of the research. Phase One tasks are designed to define the training tasks, the level of ISF automation, and the measurement and evaluation methodologies to be used in this research. Phase Two consists of both analytical and empirical tasks that are designed to identify potentially cost-effective applications of ISFs. Phase Three has the purpose of identifying training-effective applications of the ISFs identified in Phase Two. The objective of Phase Four is to develop and evaluate a prototype Program of Instruction (POI) for both student and instructor/operators that incorporates the composite findings of the first three phases. A detailed description of each of the research phases is presented in the sections that follow.

Phase One

The first phase of the research consists of four "up-front" analytical tasks. The tasks are designed to define (a) target training tasks and phases, (b) desired level of automation, (c) performance measurement requirements and capabilities, and (d) research methodology. The products of each of the Phase One analytical tasks will serve as inputs for the remaining phases of the research program.

The four tasks addressed in Phase One are highly interrelated in the sense that decisions made about one task have a major impact on the others. For instance, decisions about the degree to which simulator training is automated will have a major impact on the performance measurement capability that is required. Conversely, costs and technological constraints may place limitations on performance measurement that, in turn, may make it impossible to achieve the desired level of training automation. Because of such interdependencies, there is no

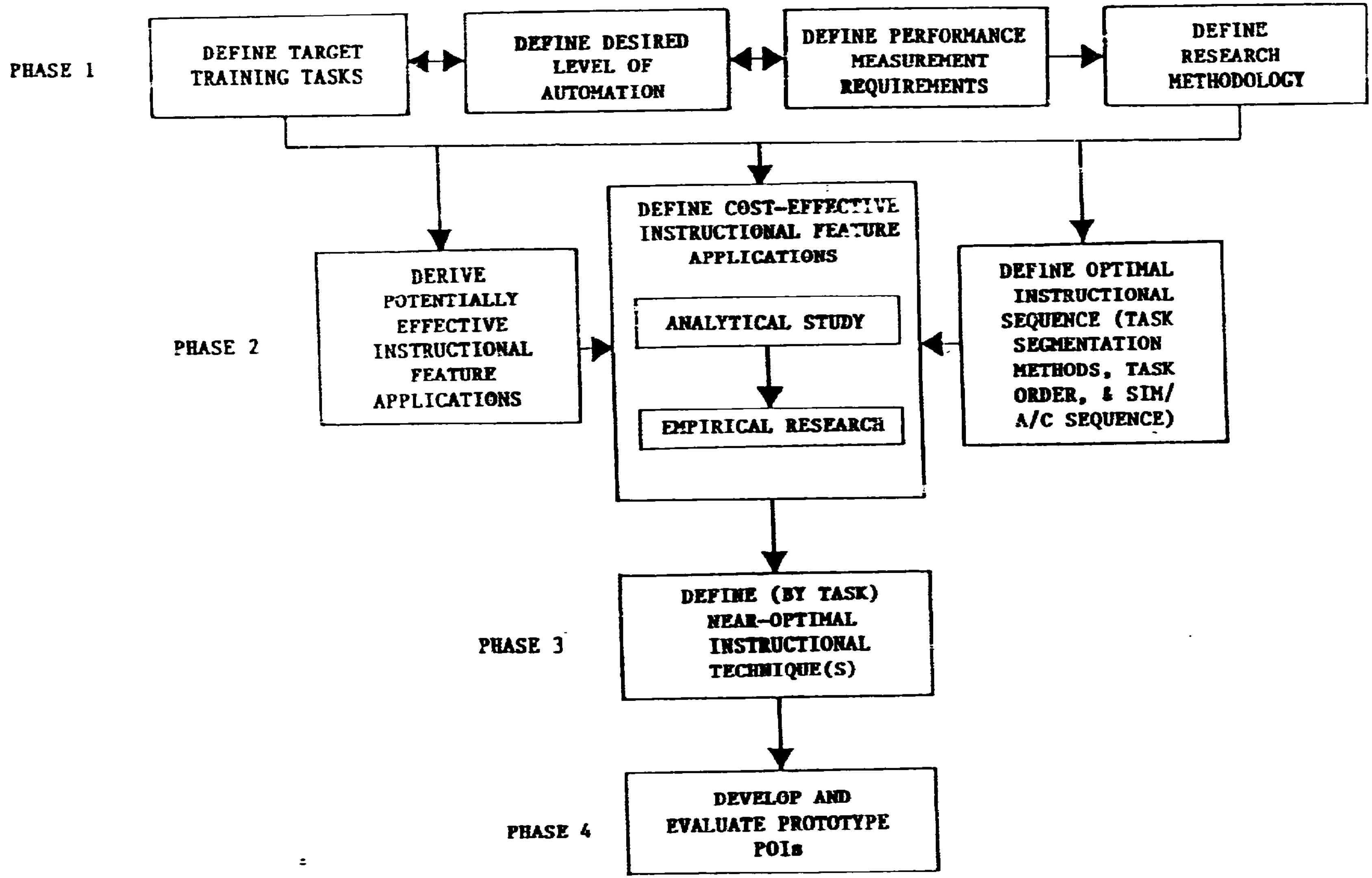

Figure 5. Task-flow diagram for research on Instructional Support Features (ISFs).

logical order in which to conduct the Phase One tasks. They must be conducted concurrently and, in all probability, several analytical iterations will be required before final decisions can be made. Data provided by this task will be used as input to each of the remaining three phases of the research program.

Define Target Training Tasks

The objective of this task is to compile a comprehensive inventory of simulator training tasks for which skill acquisition may be facilitated by the use of ISFs. These tasks are referred to hereafter as "target" training tasks. An inventory of target training tasks will be compiled for IERW training, transition training, instrument training, and continuation training.

Define Desired Level of Automation

The purpose of the second task in Phase One is to define the desired level of training feature automation. A necessary first step in achieving this objective is to make decisions about whether the simulation training is best accomplished with an instructor pilot, a simulator operator, a completely self-instructional capability, or some combination of these training management approaches. Factors that must be considered along with the training management approach include: available technology, cost, device quantities, and student throughput.

Define Performance Measurement Requirements

The third task in Phase One is the definition of performance measurement system requirements. As indicated above, the level of instructional automation judged optimal will influence performance measurement requirements.

Define Research Methodology

The objective of the fourth and final task in Phase One is to develop the research methodology to be used during Phase Two. A suitable research methodology must yield data with which to make decisions about the cost effectiveness of potentially effective ISFs, individually and collectively. Equally important, a suitable research methodology must enable the requisite data to be collected at a reasonable cost. Ordinarily, transfer-of-training data are essential for assessing the cost effectiveness of simulators or simulator components. Although transfer-of-training studies certainly would provide the data needed to assess the cost effectiveness of ISFs, such studies are so costly and difficult to accomplish that every attempt must be made to develop a suitable alternative research approach.

Because this issue is so critical, alternatives to transfer-of-training research were carefully considered in developing the research plan for ISFs. The main idea that emerged from these considerations is that most or all of the benefits of ISFs will be manifest in a reduction in simulator training time rather than a reduction in subsequent aircraft training time. Stated differently, effective ISFs should decrease the amount of time that an aviator needs to reach a given level of proficiency in the simulator; but, there is no reason to believe that an aviator trained with ISFs would require less subsequent aircraft training than another aviator trained to the same level of proficiency in a simulator without the benefit of ISFs. If this hypothesis is valid, the cost effectiveness of ISFs could be assessed by comparing the life-cycle costs of the ISFs with the dollar value of the simulator training-time savings attributable to the use of ISFs. In short, all the data needed to assess the cost effectiveness of ISFs could be collected in a simulator known to yield training transfer.

The remainder of the discussion of ISF research assumes that the only benefits of ISFs are ones that result from an increase in the efficiency with which simulator training can be accomplished. However, it will be necessary to validate this assumption before research on ISF utility is initiated.

Phase Two

The second phase of the research program is composed of three major tasks: (a) development of an inventory of potentially effective ISFs and their applications, (b) development of an optimal sequence of ISF applications, and (c) definition of cost-effective applications of ISFs. A detailed description of each of these tasks is presented below.

Derive Potentially Effective Instructional Feature Applications

The first task in Phase Two is the development of an inventory of potentially effective ISFs and applications of those instructional features. All devices in the Army's SFTS will be examined and all ISFs incorporated in these devices and their potential training applications will be identified and described. A review of U.S. and foreign military and commercial flight simulators will be conducted to identify ISFs not presently used in the Army SFTS. Potential applications of these ISFs will be specified. Finally, simulation experts and other subject-matter experts (SMEs) will be questioned about their ideas regarding training concepts for which ISF applications could be developed. The product of this task will be a comprehensive inventory of potentially effective ISF applications.

Define Optimal Instructional Sequence

The next task in Phase Two is a definition of an optimal instructional sequence. This task is included in Phase Two because of its potential contribution to the empirical research to be conducted within this phase. Three types of effort are needed to meet the objectives of the task.

The first effort will be an attempt to analyze the tasks identified in Phase One as targets for training. The objectives of the effort are (a) to identify common task "types" or groupings so that the number of research tasks may be reduced, and (b) to permit logical, analytical decisions regarding the optimal order in which tasks should be trained. To achieve these objectives, an analysis of enabling task components such as that conducted by Meyer, Laveson, Pape, and Edwards (1978) is proposed.

Given an identification of optimal task order for training, the second effort is to conduct comparisons between the analytically derived task order and the operational task order(s). The extent of the disparity between the two task orders will, in large part, determine whether there is a need to empirically compare these two task orders. The greater the discrepancy that exists between the task orders, the greater will be the need for empirical evaluation.

The third effort required to determine an optimal instructional sequence is the identification of the optimal order in which simulator training and aircraft training is conducted. In the only relevant investigation found in the literature, Ryan, Scott, and Browning (1979) found that a blocked simulation training group required significantly fewer trials to criterion (17) than either an interspersed simulator/aircraft group (28) or an aircraft-only trained group (50). The large and operationally significant differences obtained in this study, while accepted with caution, suggest the possible importance of determining optimal sequences of simulator and aircraft training.

In designing research to determine optimal sequences of simulator and aircraft training, several factors must be considered. First, it will be necessary to conduct the research in the context of both initial skill acquisition and sustainment training. Second, the effects of interspersed training might be expected to be mediated by skill level. Thus, it will be necessary to vary the point at which students who are trained initially in the simulator begin training in the aircraft, and vice versa. Finally, the frequency with which subjects switch from the simulator to the aircraft is important and must be varied experimentally. The product of this task will be the definition of an optimal training sequence.

Define Cost-Effective Instructional Support Feature Applications

The final task in Phase Two is to define cost-effective applications of instructional support features. Both analytical work and empirical work will be performed to identify ISF applications that are cost effective. The analytical components of the task are designed to reduce the number of ISF applications for which empirical data are needed to make decisions based upon cost effectiveness.

Figure 6 is a diagram of the steps to be accomplished and the decisions that will be made to accomplish the final task in Phase Two. Products of each of the earlier tasks will be used as input to accomplish the task objective.

Step One of the task consists of the development of a Target Training Task by ISF Application Matrix. Target training tasks and phases were identified in the first task of Phase One; potentially effective applications of ISFs were identified in the first task of Phase Two. The matrix will show all possible applications of the ISFs identified in Phase Two to each of the training tasks identified in Phase One.

In Step Two of this task, the known and the assumed capabilities and limitations of each ISF application in the matrix will be defined. SMEs will be consulted as necessary during the development of the definitions.

The use of SME judgments assumes that decisions about the cost effectiveness of some ISFs can be based solely upon analytical considerations. For example, it is likely that the Initial Conditions Set ISF would be judged cost effective by most SMEs. The capability to position the aircraft at any position over the available terrain eliminates the time required to fly to that position. That application alone is likely to make the Initial Conditions Set ISF a cost-effective one. Given the Initial Conditions Set ISF, a Problem Freeze ISF would likely be judged cost effective in that it enables the instructor/operator to stop the training at any point and utilize the Initial Conditions Set ISF to change position or other relevant environmental conditions. These types of decisions about the cost effectiveness of particular ISF applications can be made without extensive empirical effort.

A more empirical approach is required for ISFs whose cost effectiveness is less obvious. As the above example illustrates, certain ISFs are interrelated. Decisions about the cost effectiveness of a single ISF application must, therefore, be made in the context of other ISFs that support or supplement its utility.

A series of steps will be followed in the empirical phase of data collection. First, research scientists, simulator instructors/operators, and other SMEs will be educated about the known and assumed capabilities and limitations of each ISF application. The SMEs will then be asked to judge the potential training utility of each ISF

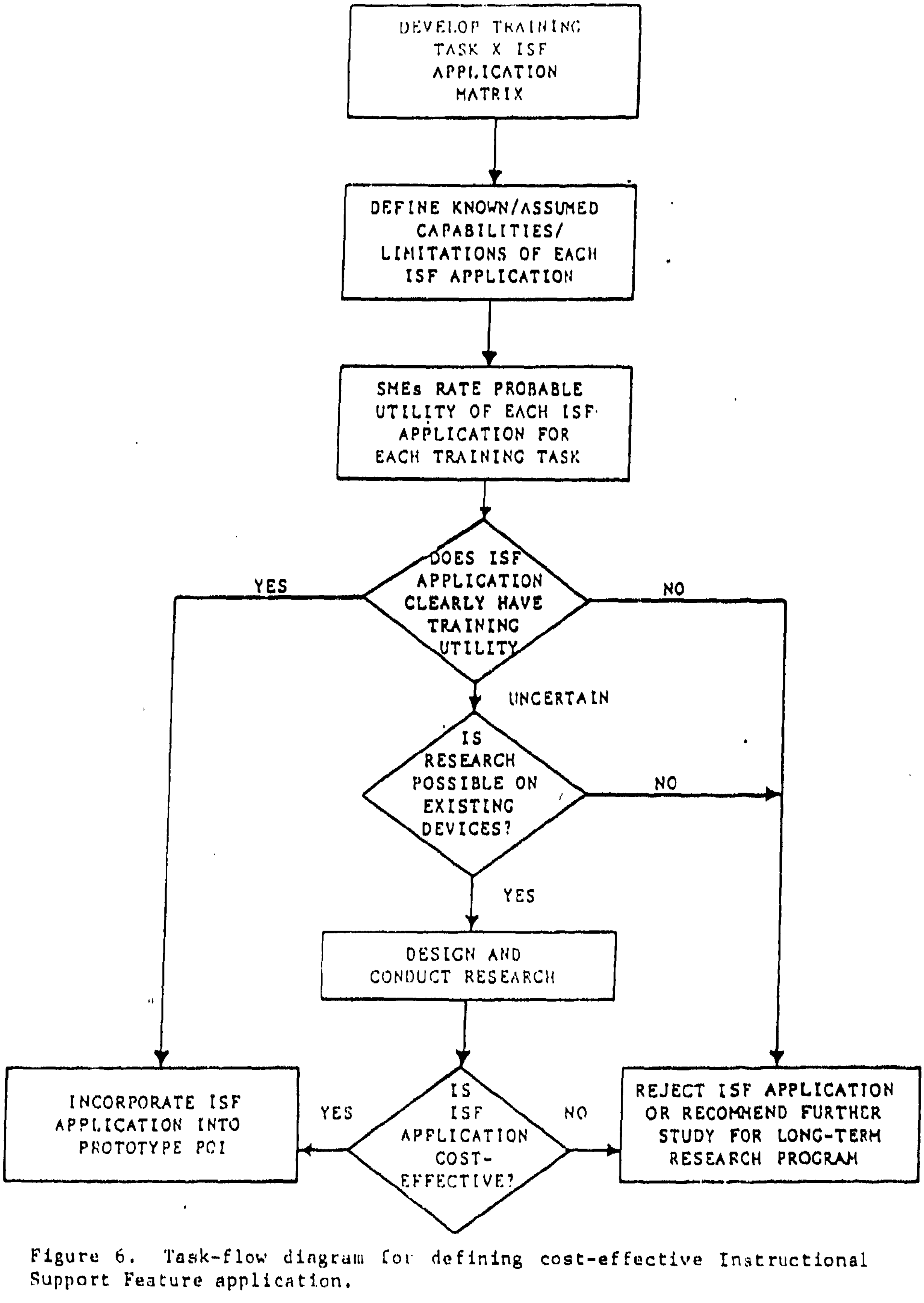

Figure 6. Task-flow diagram for defining cost-effective Instructional Support Feature application.

application on a task-by-task basis. If an application is judged to clearly have training utility for a number of tasks, the application will be selected for incorporation into a prototype POI for instructors/operators. If an application is judged to have no potential training utility, the application of the ISF will either be rejected or a recommendation will be made to study the application further within a longer-term research program. The ISF applications that remain will be those for which the potential training utility is uncertain. These applications are considered to be the best candidates for further empirical evaluation.

The inventory of potentially effective ISF applications is likely to contain several ISFs and ISF applications that are beyond the hardware and the software capabilities of the existing devices in the SFTS. Investigation of the training utility of those ISFs will be recommended as part of the longer-term research program mentioned previously.

The next step in the task is to design and conduct empirical evaluations of the cost effectiveness of the ISF applications that are within the capabilities of the devices in the SFTS. Using the general research methodology defined in Phase One, each ISF application will be evaluated in terms of its cost effectiveness when compared to appropriate control groups. The specific research designs and the measurement approaches to be used will be determined by the nature of the ISF application to be evaluated and the resources available for that effort. Applications that are found to be cost effective will be incorporated into the prototype instructor/operator POI. Applications that are found not to be cost effective will be either eliminated from further consideration or recommended for further study in a longer-term research program.

In summary, the analytical and empirical analyses in this task will provide information that can be used to make decisions about the outcomes of ISF applications. Specifically, the task results will be used to determine whether a particular ISF application will be (a) included in a prototype instructor/operator POI, (b) recommended for further study in a longer-term research program, or (c) eliminated from further consideration.

ISF applications will be included in the prototype instructor/operator POI when either of the following conditions is met:

- The ISF application is judged by SMEs to have training utility for a number of tasks.
- The ISF application is within the capabilities of the existing SFTS and is determined by empirical methods to be cost effective.

ISF applications may be recommended for further study in a longer-term research program when any of the following conditions are met:

- The ISF application is judged by SMEs to have no potential training utility.
- The training utility of the ISF application is judged by SMEs to be uncertain and the application is beyond the capabilities of the existing SFTS.
- The ISF application is beyond the capabilities of the existing SFTS and is judged by SMEs to have potential training utility.

ISF applications may be eliminated from further consideration when:

- The ISF application is judged to have no potential training utility.
- The ISF application is within the capabilities of the existing SFTS and is judged by SMEs to have potential training utility, but is determined in empirical evaluations not to be cost effective.

Phase Three

The objective of Phase Three is to define near-optimal instructor/operator training techniques. The training techniques of concern here are those techniques that are mediated by the instructor/operator and are used either alone or in conjunction with ISF applications. Examples of such instructor/operator training techniques include the type and frequency of verbal prompting, briefing and debriefing strategies, and the type and frequency of corrective and evaluative feedback. The product of this phase will be a list of instructor/operator mediated training techniques. This list of training techniques will then be incorporated into the prototype POI to be developed in the fourth and final phase of this research.

Data Collection Techniques

Two sources of information will be used to define near-optimal instructor/operator mediated training techniques. The first source of information is a review of the training literature. This review will focus upon training principles and procedures appropriate for training particular kinds of tasks. For example, research will be reviewed on prompting and fading, discrimination and generalization, practice, overlearning, intrinsic and extrinsic feedback, and the relation between these principles and transfer. Attempts will be made to relate each principle to specific tasks and/or task types. One product of this review will be an instructional program for simulator instructors/operators, utilizing relevant flight tasks as examples of how to use these principles in training.

The second, and most important, source of relevant information is the expert and successful simulator instructor/operator. It is presumed that there are simulator instructors/operators who are successful in utilizing a device to train students. It is also presumed that there are methods for identifying these individuals. Given the existence of expert and successful simulator instructors/operators, and the apparent lack of knowledge concerning that expertise in the simulation and training communities, it remains for researchers to observe the behavior of these instructors/operators. Accurate and detailed records of their activity would produce information most useful to the design of a POI for other simulator instructors/operators.

Provisions for direct observation of these instructors/operators during normal training periods would be required. An unobtrusive observer with visual and auditory access to the instructor, the student, and to relevant aspects of the device would be required. A carefully prepared and pretested behavior checklist would enable the observer to record, on a task-by-task basis, the training activities of the instructors/operators.

The products of this task will be:

- a list of relevant training principles and procedures appropriate to specific tasks, task types, or both,
- an instructional program on the use of training principles and procedures with flight tasks, and
- a description of the instructional activities of expert instructors/operators on a task-by-task basis.

The condensation of this information should, in large part, yield the data necessary to define optimal instructor/operator training techniques.

Phase Four

The objective of the fourth and final phase of this research is the development and evaluation of a prototype POI for simulator instructors/operators. The products of each of the previous phases of research will be incorporated into the design of the prototype POI.

Development of the Prototype POI

Current simulator instructor/operator training will be analyzed. The analysis will focus upon the specific syllabi, the academic training, and the simulator training conducted for instructors/operators. Program hours and formats will be examined to form a baseline for the prototype POI.

The prototype POI will be constructed as described in the third task of Phase Two, and submitted for SME review. Revisions will be made based upon the results of that review. The prototype POI will then be submitted to empirical evaluation.

Evaluation of the Prototype POI

Several alternative strategies are available to empirically evaluate the prototype POI. Decisions about the evaluation strategy, or strategies, to be employed will be made based upon the content and structure of the draft POI and the resources available to conduct the evaluation. One alternative is to move directly to an evaluation of the effect that the draft POI has on instructor/operator and subsequent student behavior. With this approach, the draft POI itself would serve as the independent variable. A two-group comparison between a POI-trained group and a current program-trained group would be conducted. Measures of both instructor behavior and student behavior in the simulator would be obtained.

A second, and perhaps more desirable, alternative is to derive testable hypotheses from the results of Phase Three. By relating the observational records of expert instructors/operators to specific training principles and procedures, several questions will arise concerning the efficacy of certain training principles and procedures. It should be possible to resolve a number of these questions analytically. The remaining questions would be stated in testable form. These questions would form the basis of a programmatic series of investigations of instructional variables. The results of the programmatic training research would serve as empirical bases for the content of the draft POI. This POI could then be evaluated with the two-group comparison described above.

A third approach to the evaluation of the draft POI is to directly test the components of the draft POI. A component analysis would allow separate determination to be made of the effects of independent segments of the POI. Emphasis here would be placed on instructor/operator behavior as the primary dependent measure. The specific constitution of the POI will determine the manner in which it is to be segmented. For example, feedback components of the POI could be introduced in one segment followed by a prompting segment and a fading segment.

Measures of feedback, prompting, and fading behaviors would be obtained throughout the evaluation procedure. Inferences about the effects of each component would be drawn by a comparison of the relevant measure prior to and following the introduction of the corresponding component of the POI. The draft POI constructed through the empirical evaluation of its various components could then be compared to the current instructor/operator training program in terms of its effect on instructor/operator behavior and on student performance in the simulator.

SECONDARY RESEARCH AREAS

The remaining portion of this section discusses nine "secondary" research areas. As was stated earlier, there are problems and uncertainties in each of these secondary areas that must be resolved in order to conduct effective research in the areas of primary concern: simulator fidelity and instructional support features. The discussion of each of the secondary research areas is aimed at defining the nature of the problems; no attempt has been made to formulate a research plan to investigate each of the problems.

HELICOPTER FLYING-TASK[13] DATA BASE

There is a great need within Army aviation to develop a comprehensive data base on the tasks that helicopter aviators must be able to perform in order to achieve full operational-ready status. Within the present context, the need for such a data base centers on the development and assessment of training methods and media. However, a comprehensive flying-task data base is also needed for:

- the development and validation of improved aviator selection tests;
- the development and validation of improved proficiency assessment measures for individual aviators, aircraft crews, multiple-aircraft teams, and combined-arms teams;
- human factors design of new aircraft and new equipment developed for use in existing aircraft; and
- the development or refinement of operational procedures and tactics.

The flying-task data requirements for each of the applications mentioned above have some unique elements, but there are a great many data requirements that are common to two or more of the applications. Due to the commonality in task data requirements, there has been an enormous amount of duplication of effort in the compilation of flying-task data by different Army and industrial organizations. In addition to the problem of duplication of effort, there have been problems with data quality and data standardization. Because of the limited resources--time, funds, and personnel expertise--that any one organization can bring to bear in compiling flying-task data, there have been instances in which the resulting data have not been as complete and valid as the user needs to do the job. Lack of standardization in the task analysis methods employed, the type of task data compiled, and the descriptors used to characterize flying tasks have resulted in

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[13] The term "flying tasks," as used here, encompasses all preflight planning tasks performed on the ground as well as all tasks performed in the air, whether or not the tasks involve control of the aircraft.

inefficiency and miscommunication when the data have been used by organizations other than the one that developed the data.

The requirements and problems discussed above point to the need for a comprehensive, standardized data base on helicopter flying tasks. The development and maintenance of such a data base would be costly. However, in the long run, such a data base would surely result in cost savings through eliminating duplication of effort and increasing effectiveness in performing jobs that require flying-task data.

Numerous technical problems must be overcome in developing a flying-task data base.[14] Probably the most difficult problem is that of creating a meaningful conceptual structure for organizing the data. Other difficult, but less formidable problems, include:

- identifying the potential users of the data base and specifying the needs of each user;
- specifying the composite set of data items needed to satisfy the requirements of each user;
- developing standardized data-collection methods, especially methods for conducting task analyses for new aircraft and new systems to be installed in operational airframes;
- developing standardized descriptors for use in defining missions, mission segments, functions, flying tasks, operator tasks, operator subtasks, operator actions, etc.; and
- specifying the manner in which the data are to be formatted, assessed, and updated.

Identify Data-Base Users/Needs

An effort to develop a flying-task data base must commence with the identification of the Army organizations that must employ such data in accomplishing their job. Then, it will be necessary to survey representatives of each organization, using questionnaires and/or interviews, to identify the types of jobs for which flying-task data are required and the specific data items needed to accomplish that job. The composite findings of the user survey will serve as the basis for formulating a set of general data-base requirements.

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[14]Many of the research problems and issues discussed by Hays (1981) and by Hays and Singer (1983) are germane to the development of a helicopter flying-task data base. Their writings have had a major influence on the ideas presented in this subsection.

Define Data-Base Structure

In developing a data-base structure, it must be kept in mind that there is no single set of data items and no single data-base organization that will be satisfactory for all users. As a consequence, it is essential that the flying-task data base be computerized and that the computerized data be formatted in a way that will enable users to organize the data in a manner that best suits their needs. Although the data will be organized and processed in various ways by various users, it is necessary to develop a conceptual structure that will (a) provide guidance in making decisions about data formatting and data accession methods, and (b) enable users to conceptualize the contents of the data base and how to go about organizing it to meet their needs. The comments presented below reflect only preliminary thoughts about a data-base structure.

As presently conceived, the mainstay of the data-base structure would be a fully comprehensive listing of mutually exclusive flying tasks.[15] Some flying tasks would be defined in terms of aircraft actions, such as: ground taxi, takeoff to a hover, steep approach, circling approach, autorotation, etc. Other flying tasks would be defined in terms of discrete tasks an aviator must accomplish on the ground (plan an IFR flight, prepare performance planning card, etc.) or in the air (perform emergency procedure for emergency landing, fire 2.75-inch FFAR rocket launcher, etc.). The concept is to define flying tasks such that they can be used as discrete "building blocks" in describing operational missions or training sessions. To be acceptably comprehensive, the flying-task listing must contain the flying tasks needed to describe any operational mission or training session for any aircraft flying under any condition in which Army helicopters might be required to operate. In short, the flying-task listing must encompass the full range of missions (including training), aircraft types, topography, weather conditions, lighting conditions, and battlefield-generated visual obscurants.

An essential requirement of the training-task listing is that the training tasks be defined at a common and useful level of specificity. The enormous variation in task specificity is one of the reasons it is difficult to use ATM tasks in designing training system research. Some

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[15]This effort is similar but not identical to the development of a flying-task taxonomy. The ideal flying-task data base would enable different users to develop taxonomies specifically tailored to their needs. That is, the fundamental tasks and associated data listed in the data base could be organized and classified in terms of a variety of different behavioral or nonbehavioral criteria. The work of Meyer and his associates illustrates the types and uses of taxonomies that could be developed from the envisioned flying-task data base (Meyer, Laveson, & Weissman, 1974; Meyer, Laveson, Weissman, & Eddowes, 1974; Meyer, Laveson, Pape, & Edwards, 1978).

ATM tasks, such as "hovering turns," are defined at such a high degree of specificity that it facilitates specific thought about methods and media that would promote training on the task. Other ATM tasks, such as "route reconnaissance," are defined at a level of specificity that is far too general to be of use for most analytical purposes. A route reconnaissance subsumes numerous other ATM tasks that differ greatly in the knowledge and skills required to master them. Such tasks must be subdivided into finer units to promote more detailed and systematic consideration of training methods and media. Variation in the level of specificity of flying-task definitions probably would create similar problems for data-base applications other than training research.

The data-base structure envisioned would consist of a very large three-dimensional matrix with flying tasks listed along one axis, aircraft types listed along a second axis, and flying conditions listed along a third axis. Each cell in the matrix would contain data elements germane to the corresponding flying task, aircraft type, and flying condition. The data items stored within each cell of the matrix are discussed in the following subsection.

Specify Data Items

Initially, the data items to be included in the data base will be specified through an analysis of the information generated by the user survey. Subsequently, user feedback will be used to expand and/or refine the population of data items. Two classes of data items are needed: flying-task descriptors and operator-task descriptors. Flying-task descriptors should include at least the following:

- a general description of the flying task for the aircraft/ condition(s) in question;
- identification of all personnel who are directly or indirectly involved in performing the flying task, including crews of other aircraft and ground personnel;
- specific performance criteria and standards for the flying task; and
- enabling flying tasks--the flying tasks that must be mastered before effective training on the task in question is possible.

The data items referred to as "operator-task descriptors" correspond closely with traditional task-analysis data. As the term implies, all operator-task descriptors are aimed at characterizing what the operator must do to accomplish a specific flying task. While by no means complete, the following list exemplifies the types of operator-task descriptors that should be included in the data base; such data will be required for each individual who participates in the flying task in question:

- verbal description of each function, task, and subtask that must be performed to accomplish the flying task in question[16];
- the exact sequence in which the functions, tasks, and subtasks must be performed, if applicable;
- the operator knowledge/skill requirements for each operator task/subtask;
- the displays that must be referred to and the controls that must be manipulated to accomplish each operator task/subtask;
- the extra-cockpit visual information required to accomplish each task/subtask;
- the nonvisual cues required to accomplish each task/subtask;
- the type and source of other information required to perform each task/subtask;
- ratings of task/subtask difficulty (to learn and to perform by trained aviators);
- ratings of task/subtask criticality (safety and mission success);
- time required to perform task/subtask (average time, maximum time, and minimum time);
- rating of task/subtask in terms of tolerance for voluntarily delaying the task/subtask when workload is high; and
- task/subtask class (control, information processing, decision making, etc.).

Not all of the data listed above are presently available; much of the data would be difficult to acquire. However, all of the data items listed are believed to be needed by one or more Army organizations. And, as was suggested earlier, there undoubtedly are other data needed that are not included in the above list.

Develop Methods for Formatting, Accessing, and Updating Data Base

Little can be said at this point about the development of methods for formatting, accessing, and updating the data except that these methods must be specifically tailored to the needs and capabilities of the users. At this point, it seems clear that the system must be designed for individuals who are relatively unsophisticated in computer operations and infrequent users of the data base. It also seems clear that the system must be designed in such a manner that enables users to easily select from the composite data base data items that are of interest and to organize the data in a way that best suits their needs.

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[16] A standardized set of verbs (acquire, control, check, engage, etc.) should be used in drafting the task/subtask descriptions.

TEAM/COMBINED-ARMS TRAINING

Current Army doctrine dictates that, when engaged in combat operations, a helicopter crew nearly always operates as part of a larger team. The team may consist of the crews of two or more helicopters, a helicopter crew and division artillery personnel, a helicopter crew and a forward air controller, a helicopter crew and the crew of a close air support aircraft, a helicopter crew and air traffic control personnel, a helicopter crew and a ground-unit commander at almost any level of command, and so on. There is considerable concern in the Army that the effectiveness of combat operations may be compromised by the lack of training on team tasks.

This subsection addresses the need for research to (a) determine the specific requirements for team/combined-arms training within Army aviation, and (b) specify the role of flight simulators in providing such training.

Background

In 1976, the Defense Science Board acknowledged the need for greater emphasis on the training of crews, groups, teams, and units throughout all branches of the armed services (Defense Science Board, 1976). The Defense Science board also acknowledged that the accomplishment of this objective will require extensive research on the nature of team performance, the methods for defining and measuring team performance, the methods for defining team training requirements, and the methods and devices that will yield effective team training. The Defense Science Board's recommendations are based on the fundamental premises that training on individual skills alone is inadequate to meet the requirements of peacetime readiness and wartime deployment, and that there are some essential skill elements--above and beyond individual skills--that can be acquired only through training and practice as a team. There is some research evidence that supports these premises (see references cited in the following paragraph). Moreover, the belief in the necessity of team training is reflected in both past and present military training practices; military training nearly always culminates in some form of multi-individual or team training.

Since the Defense Science Board published their recommendations, several Department of Defense agencies have funded efforts to review the team-training literature and to identify research that will eventually lead to improved team-training principles and practices (Denson, 1981; Dyer, Tremble, & Finley, 1980; Prophet, Shelnutt, & Spears, 1981; Thorndyke & Weiner, 1980; Wagner, Hibbits, Rosenblatt, & Schulz, 1977). These documents and others have been reviewed in an attempt to extract general observations and conclusions that have a bearing on Army aviator team training and the potential role of flight simulators in accomplishing this training. The conclusions considered relevant are summarized below.

Value of prior research. The team-training research literature is neither extensive nor current, and no research was located that deals directly with the team training of Army aviators. Although some of the prior research is of considerable theoretical interest, the results are of marginal value in answering specific questions about the types of team skills that Army aviators must possess in order to perform effectively in combat or the best way to train such skills. Hence, there is a definite need for further research in this area.

Definition of a team. The definition of what constitutes a team and the specification of the attributes that differentiate a team from a small group has received considerable attention. Thorough discussions of various definitions of a team are presented by Denson (1981), Hall and Rizzo (1975), Meister (1976), and Wagner et al. (1977). Researchers differ in their conceptual definition of a team, and those who have reviewed these definitions generally agree that there is no definition that is suitable for all circumstances. Even so, there seems to be a general consensus that the minimum characteristics for a team include:

- a goal or mission orientation,
- a formal structure,
- assigned roles, and
- a requirement for interaction between members (Hall & Rizzo, 1975).

Other factors that may prove important in deriving a suitable definition of a team include number of individuals, degree of interaction/communication, physical proximity during team activity, and the interrelationship among equipment under the control of individuals.

It should be noted that most of the contemporary definitions of a team were derived from definitions originally formulated by individuals working at the American Institutes for Research Team Training Laboratory (see Klaus & Glaser, 1968).

Established vs. emergent situations. A point on which there is uniform agreement is that the context in which team behavior occurs has a major impact on the type of team training that is appropriate and beneficial. This context is viewed as a continuum that varies from a totally "established" situation to a totally "emergent" situation. Boguslaw and Porter (1962) describe these situations in the following manner.

- Established Situation--one in which (a) all action-relevant environmental conditions are specifiable and predictable, (b) all action-relevant states of the system are specifiable and predictable, and (c) available research technology or records are adequate to provide statements about the probable consequences of alternative actions.

- Emergent Situation--one in which (a) all action-relevant environmental conditions have not been specified, (b) the state of the system does not correspond to relied-upon predictions, and (c) analytic solutions are not available, given the current state of analytic technology.

In principle, team performance in a purely established situation is solely a function of the individual skills of the team members; team training would not be expected to benefit team performance in a purely established situation. Conversely, team performance in a purely emergent situation is a function of both individual skills and team skills; the maximum benefits achievable from team training would be expected in a purely emergent situation. No team function that an Army aviator may be required to perform is likely to be purely established or purely emergent. Nevertheless, an examination of where a team function lies along the established/emergent continuum should be useful in estimating the relative benefits likely to be realized from team training on that function.

Immediate vs. extended teams. Meister (1976) has made a distinction between "immediate" teams and "extended" teams that is useful in characterizing the teams in which Army aviators may be members. The fundamental concept is that "immediate" teams are relatively small teams that are embedded in larger "extended" teams. The Army's AirLand Battle doctrine (see U.S. Army FM 100-5, 1982) defines a hierarchy of teams that will function on the modern battlefield; helicopter crews and multi-helicopter teams are embedded in "extended" teams at nearly every level of the hierarchy.

Importance of individual proficiency. It is clear from the team training research literature that individual proficiency is a prerequisite for effective team training, regardless of whether the team is operating in a predominately established situation or a predominately emergent situation (Kanarick, Alden, & Daniels, 1971; Klaus & Glaser, 1968; Wagner et al., 1977). Moreover, Horrocks and his colleagues have shown that an emphasis on coordination early in training actually interferes with the acquisition of individual proficiency (Horrocks, Krug, and Heermann, 1960; Horrocks, Heermann, & Krug, 1961). In short, it can be concluded that (a) team members should be highly trained on their individual tasks prior to the onset of team training, and (b) team training should not be used as a means to eliminate individual skill deficiencies. It follows that, when identifying requirements for team training, extreme care should be taken to determine whether deficiencies in the performance of a team are the result of individual skill deficiencies or team skill deficiencies.

Definition of team skills. There has been little progress made in defining what skills are acquired from team training that exceed the composite skills of the team members. Meister (1976) states that it is this difficulty that accounts for the fact that teamwork is not often taught in terms of skills and behaviors, but by providing a context

within which the individual practices with others. The terms most commonly cited in defining team skills include: cooperation, coordination, cohesion, team awareness, interaction, and communication. Federman and Siegel (1965), among others, have acknowledged that these terms are highly ambiguous and difficult to define operationally.

The authors of the present report have reviewed the various definitions of team skills and have compiled a listing of the specific knowledge and skill elements referred to in the definitions. This compilation was derived from the works of Alexander and Cooperband (1965); Buguslaw and Porter (1962); Collins (1977); Hood, Krumm, O'Sullivan, Buckout, Cane, Cotterman, and Rockway (1960); Kanarick et al. (1971); and McRae (1966). The specific team knowledge and skill elements identified are as follows:

- knowledge of strengths and weaknesses of team members;
- knowledge of when other team members want/need help;
- ability to pace one's actions to fit the needs of all;
- ability to behave in an unambiguous manner;
- ability to synchronize actions with others, within a time scheme or cycle;
- ability to participate effectively in solving problems for which a stock answer is not available to the team;
- inclination to cooperate;
- knowledge of team's goals;
- knowledge of the purpose and organization of the total system;
- knowledge of the relationship of one's task to the tasks of each team member;
- understanding of the characteristics and functioning of the environment and the relative importance of various events;
- ability to be innovative in better organizing team activities;
- knowledge of communication mode that is best for the task at hand;
- ability to differentiate between relevant and non-relevant communication;
- knowledge of best communication structure and pattern;
- knowledge of relevant, unambiguous vocabulary;
- ability to recognize one's own errors so as to initiate corrective actions;
- ability to recognize existing or imminent overload of self and other team members; and

- knowledge of methods for adjusting to overloads and contingencies, such as: cueing, the omission of some inputs, permitting certain errors, filtering, approximation, increasing the work flow channels, chunking information, or abandoning a hopeless situation.

Performance feedback and performance assessment. There is no question that performance feedback is as essential for effective team training as it is for effective individual training. As a result of a review of the literature on performance feedback, Kanarick et al. (1971) conclude that "performance feedback is unquestionably the single most critical parameter in team or individual training." Performance feedback has been investigated as an independent variable in several team training studies (see reviews by Denson [1981] and by Wagner et al. [1977]). Of the conclusions drawn from these studies, the ones most relevant to the present effort are (a) team performance improves more rapidly with performance feedback, (b) feedback only on the performance of the team as a whole is generally effective, but, in some circumstances, may foster inappropriate responses that result in a decrement in team performance, and (c) performance feedback on both individual and team performance is generally more effective than feedback on only one or the other.

Although the value of performance feedback is well established, there are many problems and uncertainties associated with providing optimal feedback for military teams, especially military teams being field trained in an emergent situation. Performance measurement is clearly the most critical problem. Effective performance feedback is not possible without valid and accurate measures of both individual and team performance. And yet, relatively little is known about the definition of team performance objectives, the establishment of team performance standards, and the selection and weighting of team performance criteria. The performance assessment problem is particularly difficult in emergent situations in which two or more acceptable solutions to a problem are possible. A second problem is that, given adequate performance measures, little is known about optimal methods for conveying performance feedback to team members. Post-flight debriefings and discussions is the method most commonly used at present. It seems certain that the technology presently available could be exploited to produce far more effective methods for providing performance feedback on team performance.

The Research Requirement

The immediate requirement is for research that serves to clarify the potential role of flight simulators in training the team skills that Army aviators must possess to perform effectively in combat. This research should provide data with which to (a) assess the utility of production simulators for training team skills, and (b) specify the types of design modifications that would significantly increase the

effectiveness of production simulators for training team skills. Unfortunately, it is not possible to design and conduct research that meets the immediate requirement until far more is known about the composition, structure, and functions of the teams in which Army aviators participate as team members. In other words, considerable preliminary research on team training must be conducted before it will be possible to evaluate flight simulators' role in team training. It should be noted, however, that the results of the preliminary research should be of great value to the Army, regardless of whether team training in flight simulators proves feasible. Indeed, the preliminary research, as outlined below, is nothing more than is needed to address the team training research issues spelled out by the Defense Science Board nearly ten years ago (Defense Science Board, 1976).

An Overriding Issue

A factor that may be more important than any other in determining optimal team training methods is the turnover in team membership that can be expected in a combat situation. If teams that are trained together can be expected to fight together in combat, it may be practical to provide the type of training that enables team members to tailor operating procedures and communication techniques to the unique skills, abilities, and personality traits of the team members. However, if the personnel that comprise a team can be expected to change frequently because of combat casualties or scheduling expediencies, training that results in team-specific operating procedures and communication techniques would be ineffective and probably counter-productive. A high or even moderate rate of turnover in team membership during combat dictates that personnel be trained to function in a team context rather than be trained to function as a member of a specific team. In such situations, the main team skill to be learned may be the capacity to accommodate quickly to different team members who possess different skills, abilities, and personality traits. The acquisition of such skill may require a procedure whereby an individual being trained to occupy a given team position is trained each day with a different set of team members.

The expected rate of turnover also has important implications for the need to develop highly standardized operating procedures and a standardized vocabulary; the higher the rate of turnover, the greater the need for standardization.

Research Approach

The following paragraphs outline in very general terms the tasks that are considered necessary to fulfill the research requirement cited above.

Compile inventory of teams and team characteristics. The purpose of this task is to compile a comprehensive inventory of the full range of teams for which an Army aviator may participate as a team member, and to compile data on the characteristics of each team. This task should commence with a careful review of data compiled by Dyer et al. (1980), who recently conducted an Army-wide survey to identify Army teams and to define their characteristics. The data compiled by Dyer et al. will be augmented, as necessary, with reviews of the most current documents on Army organization and tactical doctrine, and by interviews with selected personnel in Army aviation units. Although teams that include helicopter aviators are of primary interest, the survey to identify teams will encompass all types of aircraft and all types of aviation units. Moreover, the survey will be designed to identify both "formal" teams, identified in the official Tables of Organization and Equipment (TOE), and "ad hoc" teams that form frequently although temporarily on the battlefield.

For each team identified, data will be compiled to characterize the function, structure, personnel composition, operating procedures, and training of the team.

Classify teams into types. The objective of this task is to develop a scheme for clustering teams with similar attributes. Although the attributes to be used in classifying teams cannot be fully specified at this time, it is probable that at least the following attributes will be considered: team size, number of positions, ranks of team members, team function, requirement for synchrony in team members' actions, requirement for coordination, command structure, role flexibility, location of the team on the established/emergent continuum, location of the team in the combined-arms team hierarchy, expected turnover of team members during peacetime readiness training and during combat, whether the team is formal or ad hoc, and whether the team is an immediate or an extended team.

Select target teams. Once the population of teams has been identified and classified into team types, a sample of target teams will be selected for further study. The objective is to select a small set of teams that, together, cover the full range of team types and aircraft types.

Identify/analyze team tasks. For each target team, a mission/task analysis will be conducted to identify the full range of team tasks that must be performed by the team and the full range of conditions in which it may be necessary to perform the team tasks. The results of the task analysis must identify task elements, the sequence in which the task elements must be performed (if any), the team member who is responsible for performing the task element, and the equipment that must be employed to accomplish the task element.

Identify types/causes of team performance problems. A critical step in this research is to identify the types and causes of problems that target teams encounter in performing team functions. The ultimate question is: What are the problem types/causes that target teams are likely to encounter in combat? There are at least three useful sources of information about team performance problems:

- interviews with members of the target teams and their unit commanders,
- observation of team training operations, including training operations held at the National Training Center, and
- review of data compiled during recent combat operations, such as the invasion of Granada.

The results of the mission/task analyses will be used in conducting structured interviews with experienced aviators. Aviators and other individuals who comprise the team under study will be instructed to review systematically the products of the mission/task analyses and will be questioned about (a) the validity of the analyses, (b) team performance problems frequently encountered and the causes of the problems, (c) the need for team training, (d) team training requirements that cannot be met given the existing constraints on training, and (e) recommended solutions to team performance problems.

Ideally, the information compiled from the aviator interviews would be augmented with systematic observations of team training operations. Such observations could be made during routine unit-training operations and during training operations conducted at the National Training Center at Fort Irwin, California. Finally, as stated above, a careful review of the data compiled during recent combat operations, such as the Granada invasion, should yield useful information about the types/causes of team performance problems.

List problems caused by team training deficiencies. The purpose of this task is to list the team performance problems that are caused, wholely or in part, by team training deficiencies. It is expected that many of the team performance problems commonly attributed to team training deficiencies are, in fact, caused by other factors, such as: individual skill deficiencies, ineffective operating procedures, equipment limitations, and vague team objectives. Analytic study, follow-up interviews, and perhaps other techniques will be used to select, from the total population of team performance problems, those that stem from inadequate team training.

Formulate team training objectives. The results of the mission/task analyses and the results of the team performance problem analyses will be used to compile a listing of specific team skills on which Army aviators must be trained in order to ensure effective team performance. In principle, the mission/task analyses will yield a comprehensive list of the team skills that must be acquired during training; the problem analyses will yield the information needed to order the team skills in

terms of the criticality of the skill and the relative need for additional team training on that skill. All training objectives must be considered in evaluating the utility of flight simulators for team training, but team training that cannot be conducted effectively in the aircraft is obviously of special interest.

Assess feasibility/benefits of flight simulator training. The final task--assessing the feasibility/benefits of team training in flight simulators--is both difficult and complex. To accomplish this task, it will be necessary to compile data with which to answer the following questions:

- What team training can be accomplished using a single production simulator?
- In what ways can a production simulator be modified to increase its effectiveness for team training? Is it likely that the training benefits realized from the modifications will offset their cost?
- Can team skills be taught to an individual team member using "surrogate" team members (instructional personnel or a computer)?
- What team training can be accomplished in an integrated set of two or more production simulators that cannot be accomplished by using the simulators independently?
- In what ways can an integrated set of production simulators be modified to increase training effectiveness? Is it likely that the benefits realized from the modifications will offset their cost?

Answers to the above questions should initially be sought through analytic study. A team composed of SMEs in the fields of training technology, flight simulator design, and military operations and tactics should be able to identify the team training that clearly cannot be accomplished in each of the simulator configurations listed above. That is, knowledge of the team task requirements and knowledge of the design capabilities the simulators (production and modified) should enable the SMEs to accurately judge when a team task simply cannot be simulated with reasonable fidelity. However, given that a team task can be simulated, SME judgments are not adequate to assess the benefits of simulator training on that task; empirical research will be required to assess the cost effectiveness of simulator training on that team task.

A judicial decision about whether or not to embark on an extensive program of research to assess the cost/training effectiveness of team training in flight simulators must be based on (a) the type and number of team tasks that SMEs judge can be simulated, (b) the estimated benefits of the training, and (c) the estimated cost of the training, including the cost of any simulator modifications considered necessary. Even with the best of analytical data, such a decision will be difficult to make.

PERFORMANCE EVALUATION

The literature is replete with reports and articles that acknowledge that performance measurement is a major problem for both research on aviator training systems and on conduct of the training itself. Contemporary experts in performance measurement seem to agree on two important points. First, they agree that automated performance measurement systems in both simulators and training aircraft represent the ideal solution to the performance measurement problem. Second, they agree that the performance measures that the automated systems produce must be derived empirically by:

- defining an initial set of potentially useful measures,
- collecting performance data using groups of aviators, with known differences in flying proficiency for the task(s) in question,
- using multivariate statistical techniques to select the smallest, weighted combination of measures that does a good job in differentiating among the differently skilled groups, and
- validate the measures.

The methods and computer programs used to derive performance measures are available now, but they have been applied in only a few instances. The studies reported in the literature have investigated only a few flying tasks--all in fixed-wing aircraft. Furthermore, the tasks investigated to date have been ones in which it is relatively easy to define the command position and attitude of the aircraft throughout the task (maneuver) and, therefore, relatively easy to define and measure performance error (carrier landings and Instrument Landing System (ILS) approaches are examples).

Mixon and Moroney (1982) reviewed literature published between 1962 and 1981 to compile an inventory of the performance measures that have been used in research on air systems and aviator training systems. They compiled a list of 182 different performance measures that have been used in one or more research efforts. The state-of-the-art does not enable experts to identify the measures on this list that are needed to assess proficiency on a given task or the differential weights that should be assigned to each measure, and it will be necessary to complete a monumental amount of research in order to specify the types and weights of measures that provide the best index of proficiency on a given task. Herein lies the problem. Sensitive and valid performance measures are required to accomplish research on the design and use of the Army's flight simulators, and yet, this research simply cannot await the development of effective automated performance measurement systems for simulators and aircraft.

Long-term research goals should be established to conduct the basic research needed to develop automated performance systems, but the short-term research on performance measures should be aimed at making better use of SMEs in assessing flying proficiency. There is ample

evidence that SMEs are capable of assessing flying proficiency, but there are no data to use in estimating just how reliable and valid SME ratings can be if they are (a) given extensive training on performance assessment, (b) provided with clear-cut performance criteria and standards, and (c) provided with continuous records of aircraft positions and attitude throughout the task or maneuver being conducted.

ALTERNATE TRAINING DEVICES/METHODS

In the past, alternate training devices have not received the attention they deserve. Too often, flight simulators have been designed to provide training on the greatest number of flying tasks that is technically feasible; the tendency has been to consider the use of alternate training devices only when it is found that a given training requirement simply cannot be met in the simulator. When the training capability of a flight simulator is forced in this manner, the likely result is that simulator training on some tasks will be ineffective relative to training in an alternate device designed specifically to provide training on one or a small number of tasks.

The net result of the emphasis placed on large, all-purpose flight simulators is that little effort has been expended in attempting to define the tasks that might better be trained in alternate devices and attempting to apply the most current technology in designing alternate devices. It is for this reason that a recommendation is made to establish a research area that focuses on alternate training devices. The broad objective of this research area is to design and conduct research aimed at (a) identifying potentially effective applications of alternate training devices, and (b) developing potentially effective design concepts for alternate training devices.

Another objective of this research area is to provide estimates of the cost and training effectiveness of alternate training devices. As has been stated previously, the cost effectiveness of training in a flight simulator cannot be evaluated fully without considering the cost and training effectiveness of alternate devices. Although essential for the success of this program, the task of estimating the cost and training effectiveness of alternate training devices is a difficult one. Such estimates are particularly difficult when the alternate training device being considered is one that has not yet been developed and tested. In such cases, the only apparent ways to formulate cost- and training-effectiveness estimates are to depend upon the judgment of SMEs or to construct a prototype device and test it. The first approach is subject to large errors and the second is both costly and time consuming. So, a second important objective of this research area is to design and conduct the research needed to develop more effective methods for estimating the cost and training effectiveness of alternate training devices prior to their development and empirical evaluation.

SUBSYSTEM STANDARDIZATION/MODULARIZATION

There are many ways to achieve cost savings in the design of flight simulators. For the most part, this research program is aimed at achieving cost savings by identifying and eliminating unnecessary fidelity in simulator components. A complementary approach to cost savings is the modularization and standardization of hardware and software components that are common to all or most flight simulators.

At present, the design costs of many types of hardware and software are being reduced by utilizing, when possible, standardized components that are readily available on the market. It seems probable that similarly great savings can be realized if standardized components are developed and used in producing new flight simulators. This would require that effort be expended in subdividing a flight simulator into functional modules and in designing standardized modules that could be used as building blocks in developing new flight simulator systems. Examples of flight simulator components that might be designed as standardized modules include: computers, power systems, motion systems, external visual displays, cockpit superstructure, selected cockpit displays, aerodynamic modules, and instructional support features.

Use of standardized modules in producing new flight simulators has the potential for reducing both the cost of initial development and the cost of operational support. Moreover, the standardization of interface connectors, signal communication protocols, and certain physical attributes of modules would facilitate the flight simulator modifications needed to track modifications of the operational aircraft.

RESEARCH METHODOLOGY

The discussion of the long-term research plan frequently points to the need for improved research methodology. This subsection consolidates and, in some cases, expands on earlier comments about the need for more efficient and more effective research methodology.

Alternatives to Transfer-of-Training Methodology

The requirement for more efficient research methodology stems mainly from the fact that transfer-of-training research is often too costly, too time consuming, and too difficult (administratively) to justify its use. This is particularly true when research is required to evaluate hardware design options, instructional design options, or both. When the number of options to be considered is large--as is the case with the research proposed in the long-term research plan--it may be prohibitively expensive to evaluate every option using a series of transfer-of-training experiments. And yet, proven alternative methodologies are not available.

As a consequence, there is an urgent need for the Army to initiate an effort aimed at developing and validating more efficient methodologies designed specifically to reduce design options to a number that can be evaluated with transfer-of-training research without the expenditure of excessive resources. It is important to emphasize that it is not being suggested that methodologies can be developed that would eliminate the ultimate need to conduct transfer-of-training research to assess the cost effectiveness of one or more alternative devices/methods. Rather, it is being suggested that more efficient methodologies can be developed that would enable researchers to make valid judgments about which design options should be included in the transfer-of-training research.

Listed below are alternative methodologies that have been mentioned in other subsections of the long-term research plan or elsewhere (see, for example: Caro [1977b]; Caro, Shelnutt, & Spears [1981]; and Hays & Singer [1983]). This list is meant to be illustrative rather than comprehensive.

- Device-to-device transfer--using aviator trainees as subjects, measure training transfer from the device/condition under investigation to a device/condition in which training is known to transfer to the aircraft.
- Backward transfer--using experienced aviators as subjects, measure the relationship between performance in the aircraft and performance in the device under investigation.
- Similarity of response characteristics/strategies--using experienced aviators as subjects, compare response characteristics/strategies in the device under investigation with the response characteristics/strategies in the aircraft.
- Skill acquisition in device--using aviator trainees as subjects, measure the rate and amount of skill acquisition that occurs as a function of training/practice in the device under investigation.

Caro (1977b) and Hays and Singer (1983) have discussed the shortcomings of the above methodologies and others as well. They share the view that the above methodologies have low validity when used as the sole means for evaluating the training effectiveness of a device. However, the risk associated with the above methodologies, or any other, depends upon how the resultant data are interpreted. There is no question that the risk of drawing invalid conclusions is excessive if data indicating "good" performance (high rate of skill acquisition, high level of backward transfer, etc.) in a training device is taken as proof of the device's training effectiveness. For instance, evidence of skill acquisition in a flight simulator does not necessarily mean that the aviator trainee is acquiring skills that will transfer positively to the aircraft. On the other hand, the risk of drawing invalid conclusions is much lower if data indicating "poor" performance is taken as evidence that the device lacks training effectiveness, either because of the

device's design or because of the manner in which it was used. For instance, if performance in a flight simulator fails to improve significantly with practice, it is difficult to imagine that the trainee is acquiring skills that would transfer positively to the aircraft.

An effort to develop improved methodologies should commence with a literature review and a survey of SMEs to identify potentially useful methodologies. Then, empirical research should be conducted to determine the validity of the methodologies for various uses--particularly for use in the preliminary screening of options for training devices and training methods.

Improved Transfer-of-Training Research Designs

Regardless of the types of research that are conducted in designing a flight simulator, final decisions about the relative and absolute utility of alternative designs must be based on their cost effectiveness. As is well known, cost effectiveness is a function of (a) the costs of training in the simulator and the aircraft, and (b) the extent to which simulator training transfers to the aircraft. This subsection is focused on research designs that yield the requisite transfer-of-training data.

The design of a transfer-of-training study is a simple matter if the intent is merely to measure training transfer from a prescribed simulator-training curricula to the aircraft. However, the classical transfer-of-training paradigm (see Appendix E) is appropriate only when the simulator-training curricula is known to be near optimal. This is seldom the case. When designing transfer-of-training research to evaluate new simulator designs, a researcher cannot be expected to possess the information needed to develop curricula that takes full advantage of the simulator characteristics. The researcher cannot ignore the problem because a poorly designed training curricula can degrade training transfer to such an extent that even major differences in the training effectiveness of alternate designs would be masked. Furthermore, estimates of cost savings resulting from simulator training would be totally invalid if an ineffective curricula were employed.

So, when designing research to assess the transfer-of-training of one or more new simulator designs, the researcher is forced to consider such questions as:

- What tasks must be trained in the simulator?
- In what sequence should the tasks be trained?
- How much and what type of training should be given for each task?
- Should all simulator training be completed before the trainee receives any training in the aircraft, or should simulator training and aircraft training be alternated? If simulator/

aircraft alternation is beneficial, what is the best alternation schedule?

- What is the optimal way to use the simulator when there is insufficient time during the training day to provide every trainee with an optimal amount of training on every task?

The above questions must be considered for each type of training that may be conducted in the simulator: initial acquisition of flying skills, maintenance of flying skills, and relearning of flying skills.

It can be argued that the above mentioned questions should be answered through a series of analytic or transfer-of-training studies prior to conducting a transfer-of-training study to make a final assessment of the simulator's cost effectiveness. However, it can also be argued that more sophisticated transfer-of-training designs can be developed that would provide the data needed to develop predictive models. These models, in turn, could be used to predict cost and training effectiveness for a variety of training curricula. The Army has made some progress in developing this type of training-device evaluation methodology (Bickley, 1980a). However, there is a pressing need for the Army to expand upon this work.

Before concluding this subsection, it is important to emphasize the need to develop research methodologies for assessing the utility of simulators for maintaining flying skills (continuation training). The bulk of Army flight time is devoted to skill maintenance rather than initial skill acquisition, so the use of simulators for continuation training has the potential for yielding great savings. And yet, little effort has been expended by the Army to develop effective research designs for assessing the cost effectiveness of simulators used for continuation training.

SKILL DECAY/MAINTENANCE

Along with all other DoD agencies, the Army is faced with two competing objectives: maintain combat readiness and minimize operating costs. In Army aviation, the problem is acute in that individual combat readiness is presently being maintained through a program of "continuation" flight training conducted in aircraft that have unavoidably high operating costs.

The bulk of Army flight time is devoted not to initial acquisition of flying skills but to the maintenance of these skills. As a consequence, the use of flight simulators for maintaining the individual flying skills of unit aviators promises to yield substantial dividends. The potential dividends of incorporating simulator training into the Army's continuation training program are of three types:

- reducing total training costs by replacing aircraft training hours with simulator training hours,

- increasing individual skills by enabling unit commanders to allocate the flying hours saved by simulator use to training on individual flying skills that are better trained and maintained in the aircraft, and
- increasing overall unit readiness by enabling unit commanders to allocate the flying hours saved by simulator use to training on requisite combat skills, such as team operations, that presently are deficient or are not addressed in the program.

If training managers are to make judicious decisions about the use of simulators for continuation training, they must have a clear knowledge of (a) the rate at which individual flying skills decay when not practiced, and (b) the amount and type of training required to prevent skill decay or to refresh skills that have been permitted to decay. Although a substantial amount of research on skill decay and maintenance is reported in the psychological literature, the tasks investigated are not sufficiently germane to helicopter flying tasks to enable training managers to use the data to establish a continuation training program that makes optimal use of a simulator. This subsection argues the need for the Army to establish a research program to eliminate this critically important knowledge deficiency.

Skill Decay

There is a consensus among aviators that flying skills decay, but which skills decay and the course of that decay remain open questions. In an extensive review of research conducted in the general area of flight skill retention, Prophet (1976) concluded that, in general, basic psychomotor flight skills show little if any decrement over extensive periods of nonflying. However, flight tasks with a significant procedural component (such as instrument flight) suffer an appreciable decrement in as little time as three months.

Several factors were identified in mediating skill decay. Probably one of the most significant is initial skill level. That is, all other things considered, the higher an aviator's skill level prior to a period of no flying, the higher it will be at the end of that period. This has since been indirectly borne out in work involving retraining reserve Army aviators. In retraining Army aviators who had not flown for two to nine years, Allnutt and Everhart (1980) found that flight hours required to retrain were a function of total flight hours accumulated prior to layoff from flying. Total flight hours in this case was considered an indicant of skill level achieved prior to onset of the period of no flying.

Use of a gross measure such as total flight hours as an indicant of skill level is typical of work done in this area. Although the principle that overtraining improves retention is easily derived from laboratory studies of human learning and memory, what constitutes

overlearning of flight skills is unclear. There are several models of the development of skilled behavior (e.g., Fitts, 1962; McRuer & Krendel, 1974); most of them postulate various qualitative "stages" of learning. Each of the stages is characterized not so much by "what" the learner does as by "how" he does it. The highest stage is usually characterized by skilled, automatic behavior requiring a minimum of conscious attention; lower stages are characterized by conscious attention to performance. Most independent variables, such as career flight hours, and most dependent variables, such as trials or time to proficiency, would be insensitive to differences or changes in "how" some behavior, such as a normal approach, is performed. Thus, as Prophet (1976) implies, a skill may decay differentially over time, depending upon the stage to which the learner had progressed prior to layoff.

Duration of the layoff period (period of no flying) is another mediating factor discussed by Prophet (1976). For Army aviation, the critical issue is the effect of varied periods of layoff on skill loss or, in other words, the rate at which skills decay as a function of time without practice. As indicated above, skills in continuous control tasks are lost much more slowly than are skills in procedural tasks. But at present, the Army has no empirical data base on decay rates for either type of skill. The only work in this area is a study by Ruffner and Bickley (1983), which is now being prepared for publication. In this study, a group of active Army aviators was restricted from flying for periods varying from two to six months. For the set of basic maneuvers examined, this study will give indications of the degree of operationally relevant skill decay to be expected of qualified Army aviators, at least for periods of no flying up to six months in duration.

However, because of the limited scope of Ruffner and Bickley's (1983) study, the Army still will lack data on decay rates for (a) instrument flight tasks, which are primarily procedural; (b) special tasks, such as weapons delivery; (c) special conditions, such as aided or unaided night flight; and (d) all flying tasks for layoff periods that exceed six months. It will be difficult to conduct the research needed to compile the additional data on skill decay. As has been discussed earlier, in order to assess skill loss, it must be allowed to occur. However, allowing skill loss to occur in active Army units is in direct conflict with the Army's higher mission of maintaining combat readiness. Commanders are understandably reluctant to participate in studies of this type.

Skill Maintenance

Quantification of skill decay rates is but half the problem. Once the decay-rate data are in hand, the most effective means of maintaining the requisite skill levels, which would otherwise decline, must be determined. Again, there is no empirically determined data base to use

in addressing this problem. The present Aircrew Training Manual (ATM) (Department of the Army, 1980) specifies, for each aircraft task, the number of iterations recommended per six-month period to maintain proficiency. However, these recommendations are based on the consensual estimates of training experts. The results of the Ruffner and Bickley (1983) research should provide a starting point for this work, since it systematically varied the amount of training aviators received over a six-month period.

Research Requirements

It seems safe to conclude that, although probably the most lucrative target for simulator training, the area of skill maintenance through simulator training has been largely neglected. There is a clear and pressing need for research to (a) identify the flying skills that are subject to decay over time, (b) quantify the rate at which skill on each task decays as a function of mediating factors such as initial skill level and length of the no-practice period, (c) identify the optimal use of simulators, aircraft, and other training media in preventing skill decay and in refreshing skills when decay is unavoidable.

The first task that needs to be completed is to examine all existing data and summarize the conclusions that can confidently be drawn from the data. Due to Prophet's excellent review published in 1976 and the paucity of research conducted since that time, the review and synthesis of the relevant literature is not considered a major undertaking.

A second task is to survey the research designs that have been used to assess the decay/maintenance of flying skills of experienced aviators and to identify or, if necessary, develop research designs that are suitable for conducting research on skill decay and maintenance in experienced Army aviators. Various methodologies have been proffered for assessing the effectiveness of simulation for sustaining skills (e.g., Lockwood and Craddock, 1982; McMullen, 1983). Most of them are some variation of a regression analysis predicting proficiency as a joint function of aircraft and simulator training, but all are expensive in terms of time, number of test participants, and impact on combat readiness.

A third task is to formulate specific recommendations about the research on skill decay/maintenance that needs to be conducted within the context of this research program and apart from it. It is essential that these recommendations take into account both the methodological and administrative problems that must be overcome in order to accomplish the research. Careful study will be required to develop a research plan that (a) is methodologically sound, (b) yields the full complement of data that are required, and (c) is acceptable to the Army officials who must provide the requisite resources.

IMPLEMENTATION/MONITORING OF SIMULATOR TRAINING

Research is needed to develop better methods and procedures for introducing new flight simulators into the Army's aviator training system and for ensuring that the simulator continues to be used properly throughout its lifetime. Improved methods and procedures must be developed to ensure that simulator procurement, development, evaluation, and fielding proceeds on a timely schedule that matches the training need. In addition, improved methods and procedures are needed to ensure that (a) optimal training techniques are defined prior to placing the simulator in the hands of the operational user, (b) operational users do, in fact, adopt the recommended training techniques, and (c) operational users continue to employ the recommended training technique throughout the life of the flight simulator.

COST-EFFECTIVENESS ASSESSMENT SYSTEM

In the past, most of the cost-effectiveness analyses performed within the context of the Army's aviator training system have been designed to assess the cost effectiveness of a single component of the training system--in isolation from the remaining components of the system. This is particularly true for flight simulators. Although there is no question that the results of these analyses have yielded data that have been useful to training managers, there are a number of shortcomings inherent in this approach. The shortcomings stem mainly from the fact that the components of the training system are interdependent. That is, modifying one component of the training system has the potential for affecting the training effectiveness, and thereby the cost effectiveness, of other components of the system. In such a situation, a device that subsumes the training function of one or more of the other components of the training system may appear highly cost effective when evaluated in isolation. And yet, the device may actually decrease the cost effectiveness of the training system as a whole.

Another shortcoming of single-component analyses is that ancillary costs are likely to be overlooked in estimating the cost of the component. Ancillary costs likely to be overlooked in single-component analyses are those associated with any change in the training system. Examples of such costs are: the cost of modifying computer software, the cost of retraining maintenance personnel, the cost of retraining a cadre of instructors, and the cost of redesigning POIs. Clearly, the failure to consider such ancillary costs could result in erroneous conclusions about the cost effectiveness of a component of the aviator training system.

A final shortcoming of single-component analyses is that the approach does nothing to promote the identification of the optimal media-mix. Although research methods and analytic techniques have been developed to define the optimal mix of simulator training and aircraft training (Bickley, 1980b), the Army has made no attempt to develop

methods for defining the optimal mix of all components of the aviator training system.[17]

The above considerations point to the need for a cost-effectiveness assessment system that takes into account all components of the Army's aviator training system. The assessments of the benefits of new components (devices) is certainly one important function of the envisioned cost-effectiveness assessment system, but there are a host of other benefits of such a system. The following paragraphs discuss (a) the most important functions that would be served by a cost-effectiveness assessment system, (b) the availability of techniques for developing a cost-effectiveness assessment system, and (c) the generic tasks required to create and implement such a system.

Function of the System

The general function of a cost-effectiveness assessment system is to provide training managers with the information they need to make decisions about the cost effectiveness of proposed new training components or proposed modifications of the design or use of existing components. In addition, the assessment system must provide information with which to continuously monitor the aviator training system and to identify problems that affect training costs. Examples of such problems include, but are not limited to, changes in the abilities of training personnel, changes in the effectiveness with which the training devices are actually employed, and changes in the procurement costs or maintenance costs of devices. The system also must enable training managers to anticipate problems that might arise in the future, given specific assumptions about factors such as mission, tactics, and the size of the force.

The cost-effectiveness assessment system should yield bottom line answers based on the actual amount of training produced per dollar of expenditure. These answers should be derived from an assessment of how the entire system will be affected by a proposed addition or modification.

Need for Sequential Refinement and Continuous System Monitoring

The system must be designed such that it "learns" as data are accumulated. This design feature, sometimes referred to as "artificial

[17]The Air Force has recently funded research aimed at developing linear optimization models for use in evaluating an entire training system, including defining the optimal mix of all components of the training system (see Marcus et al., 1980).

intelligence" or "heuristic programming,"[18] is a refinement of an old technique called sequential analysis. However, there is an important difference in the function served by the two techniques. The base function of sequential analysis is hypothesis testing; data are input until an hypothesis or alternate hypothesis is rejected. The function of heuristic programming is to refine a model or to derive more accurate estimates of key parameters of a model. As in sequential analysis, the heuristic program does not replace old data when new data are input: the program continues to use all available data.

Availability of Necessary Theory and Mathematical Techniques

The mathematical techniques needed to design and implement the cost-effectiveness assessment system are available and are well known to the operations-research community.[19] The techniques include, but are not limited to, the following:

- linear and non-linear programming,
- linear and non-linear goal programming,
- dynamic programming,
- network models, and
- forecasting.

All of the techniques are scientific production methods. Since the Army is in the production business--the production of training--scientific production methods are entirely appropriate. A brief description of each of the above techniques will serve to illuminate the need for scientific production methods.

Linear and non-linear programming. Linear and non-linear programming techniques are designed to optimize an objective function subject to specified constraints. Cost data for each variable of interest are entered into the function and the function is either maximized (amount of training) or minimized (training costs), subject to the specified constraints. The most common constraints stem from resource limitations. Constraints are stated in the form of equalities or inequalities such as the following:

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[18]A heuristic program is a program that learns as it is used. The usual procedure is to input historical data, let the program generate solutions, then input the actual solutions. At this point, the program makes adjustments to the variables and parameters which it uses so that it gives better solutions in the future. This cycle (input data - generate solutions - input actual solutions - adjustments) continues during the life of the program.

[19]Readers interested in a more detailed discussion of these techniques are referred to the textbook by Wagner (1975) and to the extensive bibliography presented on pages 998-1026 of his book.

- total-hours-of-training-per-month = 3000, or
- available-hours-of-IP-time ≤ 3300, or
- training-hours-per-student ≥ 100

The inequalities are changed to equalities by the introduction of "slack" or "surplus" variables and the resulting set of simultaneous linear equations are solved such that the objective function is optimized. In other words, the objective function is optimized subject to the availability of resources.

In linear programming, the objective function and each constraint must be linear. Exponents and cross-products are excluded in the problem statement. Non-linear programming is not restricted by the requirement for linearity.

Goal programming. Goal programming is essentially an extension of linear and non-linear programming methodology. The technique enables the user to specify multiple goals (objective functions) and to assign priorities to each goal. Within the present context, goals for a goal programming analysis might include minimizing costs, minimizing training time, and minimizing fuel usage. In goal programming, each goal is assigned weights or priorities such that the optimization of all goals (weighted accordingly) is achieved as nearly as possible, subject to the constraints.

Network models. Network models are designed to yield solutions to problems such as finding the shortest path, the least costly path, or the shortest duration path from an origin node to a terminal node. The network consists of a set of nodes, pairs of which are connected by directed arcs. The mathematical solution to the problem is a special case of an assignment model.

Within the context of the Army aviator training system, network models might be employed to identify the most cost-effective path from the origin (a class of untrained student pilots) to the terminal (a graduating class of trained pilots). In other words, network models might be used to define the training sequence that utilizes the classroom instruction, flight simulator training, aircraft training, and training on other devices in the most cost-effective manner. The objective of such an analysis is to define the order of the various training tasks that optimizes the cost effectiveness of the overall training program.

Dynamic programming. Dynamic programming is an extension of network modeling. The technique adds another dimension--time--to the network model. Dynamic programming problems are solved by the same methods employed to find solutions to network problems. The difference between the two techniques is that dynamic programming problems are characterized in a way that clarifies their dynamic (time-related) properties.

To illustrate how dynamic programming might be used, suppose that a proposal is made to add a visual component to a flight simulator and that the visual system has been shown to contribute positively to the cost effectiveness of the system as a whole. Dynamic programming could then be used to schedule the various tasks required to bring the visual component on-line in the most cost-effective manner. This technique could be used in scheduling such tasks as reprogramming the computer, training maintenance personnel on the visual component, and revising the POI.

Forecasting. Forecasting, a common technique, is a necessary function of a cost-effectiveness assessment system that is to be used to monitor and predict the final output of the training system (training per dollar). Continuous data input is critically important because moving average, weighted moving average, exponential smoothing, and linear/non-linear regression are statistical techniques that use sequential data input to improve forecasting.

Overview of Requisite Tasks

Conduct user survey. An essential first step in developing a cost-effectiveness assessment system is to survey individuals within the Army who would be expected to use such a system. The main objective of the user survey is to identify the full range of decisions that might be made more objectively or on a more timely basis with the aid of a cost-effectiveness assessment system.

Define system functions. The user survey will provide the basic information needed to define the functions to be served by the system. Generic functions of the system that can be identified at this time include:

- define the impact on training costs of proposed changes to the aviator training system,
- define the optim l mix of a specific set of training media,
- identify the principle cost drivers within the aviator training system,
- continuously monitor the aviator training system for the purpose of detecting unexpected changes that influence the costs and/or effectiveness of changes,
- develop optimal methods for implementing desired changes to the aviator training system, and
- forecast future training costs based upon assumed changes in training requirements and/or assumed changes in personnel and materiel costs.

Develop preliminary model. The next subtask to be accomplished is the development of a preliminary model. The intent is to define an

idealized model in the form of a function-flow diagram. The function-flow diagram must be defined in sufficient detail to (a) identify the type of data/information required to implement the model, (b) define the data processing and analysis requirements, and (c) define the type and form of the model's outputs.

Determine type, form, and accessibility of existing data. A survey of Army agencies will be conducted to determine the type, form, and accessibility of the data needed to implement the cost-effectiveness assessment system. The problems associated with obtaining accurate cost data from training-equipment contractors must be addressed at this point. For some applications, it will be necessary to obtain from contractors data on the cost of training devices or individual components of training devices. Obtaining such data is complicated by the fact that contractors are understandably reluctant to reveal information that could benefit their competitors. Hence, considerable thought must be given to methods for deriving accurate equipment cost data, especially for equipment in the conceptual stage of development. The product of this task is a listing of the requisite data that are presently available and a listing of the requisite data that are not presently available. For data that are available, the listing will specify the source of the data and the suitability of the form of the data.

Define data compilation methods. The purpose of this task is to formulate methods for compiling the data required to implement and maintain the cost-effectiveness assessment system. Of particular importance is the identification of the changes in the Army's existing record keeping systems that are required to provide the type of data that are needed in a form that is needed.

Develop detailed model. Work on the development of a detailed model will be commenced only if the results of the previous subtasks indicate that the data needed to exercise the model can be compiled at an acceptable cost. Otherwise, further work should either be terminated or delayed until data support becomes feasible. It would be premature to define the specific modeling techniques that should be employed. It is likely, however, that some of the techniques described in the subsection entitled "Availability of Necessary Theory and Mathematical Techniques" will be used.

Validate and refine model. It is important to keep in mind that the model will be dynamic in nature: changes and additions must be made routinely. Once the basic model is in place, an initial validation phase will be implemented. Historical data will be used to validate the integrity of the model and to point out faults and omissions. The validation and refinement must be an ongoing process. The heuristic qualities of the model, along with sequential data input, will help to ensure better solutions as time passes. The type of information needed by system managers for decision making should also be constantly monitored to ensure that the model will be responsive to the needs of the decision makers.

SECTION III

RESEARCH TO OPTIMIZE DESIGN AND USE OF PRODUCTION SIMULATORS (SHORT-TERM PATH)

As was stated in Section I, the Short-Term Path is a program of research that is aimed at evaluating and optimizing the use of the family of flight simulators that the Army already has acquired or has contracted to purchase. Since the design of this family of simulators is more or less fixed, the research is focused mainly on ascertaining how best to use the devices: who should be trained, what tasks should be trained, how much training should be administered, and what training methods should be employed for each training application. This does not mean that design issues will be ignored altogether. Indeed, an important secondary objective of the Short-Term Path is to identify design modifications (hardware and/or software) that will improve the training effectiveness of production simulators without incurring excessive product improvement costs.

This section begins with a description of research designed to determine the optimal use of flight simulators in a unit-training context. Unit training refers to the training received by Army aviators after they have completed institutional training and have been assigned to an operational unit. Unit training includes, but by no means is limited to skill-sustainment training.

The next major subsection described a program of research that focuses on the use of flight simulators to train contact flight skills to beginning flight students. The final subsection describes a program of research whose purpose is to determine the extent to which Night Vision Goggle training can be accomplished in a flight simulator equipped with a visual system. Although the Night Vision Goggle research is to be conducted in an institutional training context, the results should be useful in determining how best to use simulators to train Night Vision tasks in a unit-training context.

RESEARCH TO ASSESS APPLICATIONS/BENEFITS OF AH-1 FLIGHT SIMULATORS FOR OPERATIONAL-READINESS TRAINING

INTRODUCTION

This document describes a plan of research that has as its general objective the assessment of the benefits realized from using flight simulators to train field-unit aviators. This introductory subsection discusses the background and focus of this research, the assumed role of flight simulators in a unit-training environment, and potential applications of flight simulators in accomplishing unit training. The following subsection describes an interrelated series of analytical studies and empirical experiments that, together, will fulfill the objectives of this project.

Background

The Army's Synthetic Flight Training System (SFTS) has been audited by the Army Audit Agency (AAA) on two occasions: first in 1981 and again in 1984. The results of the first audit are described in AAA Audit Report SO 82-6, (U.S. Army Audit Agency, 1982); the results of the second audit are summarized in a letter from the Southern Region U.S. AAA to the Assistant Secretary of the Army for Research, Development, and Acquisition (27 August 1984).

The overriding issue in both audit reports was the number of flight simulators that are required to support the training of field-unit aviators. Specifically, the AAA concluded that the unit-training requirement can be met with fewer flight simulators than are specified in the Army's Basis of Issue Plans (BOIPs). In their audit reports, the AAA has strongly emphasized that both the BOIP and the AAA analyses of flight simulator requirements are based on only the most vague information about the roles that flight simulators are to play in unit training. As a consequence, the AAA has strongly urged the Army to undertake the research needed to quantify the return on the Army's investment in flight simulators that are to be used solely to train field-unit aviators.[20]

It is generally recognized that five factors must be considered in assessing the return on the investment in flight simulators:

- the cost of acquiring, housing, operating, and maintaining the flight simulators;
- the cost of transporting unit aviators to the flight simulator;
- the number of aviators to be trained in the flight simulator;

[20] The return on investment in flight simulators used for institutional training was not questioned by AAA and, therefore, is not among the issues addressed in this research plan.

- the amount of flight simulator training each aviator will receive; and
- the benefits of the flight simulator training.

Information on the first three factors is available or can easily be obtained. However, little information is available on the last two factors: the amount of flight simulator training unit aviators should receive, and the benefits of the flight simulator training. It is these two factors that are the primary concern of this research. Specifically, the research has been designed to generate data with which to specify the type and amount of training that unit aviators should receive in flight simulators, and, to the extent possible, quantify the benefits of this training.

Focus of Research

Early in the research planning process, it was concluded that the initial research should focus on a single flight simulator, and that the AH1FS is more suitable for this research than any other flight simulator now fielded (UH1FS and CH47FS) or soon to be fielded (UH60FS). The reasons for focusing on a single flight simulator are twofold. First, conducting research on two or more simulators concurrently would require more research personnel than can easily be mustered. Second, conducting research on two or more flight simulators concurrently would result in unnecessary duplication of effort. That is, it is believed that much of what is learned from the initial research on the AH1FS can be generalized to other rotary-wing flight simulators of similar design that are to be used for unit training.

Factors considered in selecting the single most suitable flight simulator include: the number of unit aviators available to participate in the research, the number of simulators available at field-unit locations, and the range of tasks that are potentially trainable in the flight simulator. On all three counts, the AH1FS was judged more suitable than the CH47FS, or the UH60FS. The UH1FS does not qualify as a candidate, mainly because UH1FSs are not equipped with a visual system.

Role of Flight Simulator Training

The research proposed herein is based on the fundamental premise that the role of the flight simulator is to augment rather than replace aircraft training. At the time the Army's SFTS was conceived, it was assumed that the use of flight simulators would reduce the aircraft hours and the munitions required for unit training. Since that time, however, there has been a steady decrease in the flying hours and munitions allotted to unit training and a dramatic increase in the level of skill required to function effectively on the modern battlefield.

Consequently, it is unrealistic to expect that the use of flight simulators will result in a further reduction in either the aircraft hours or the munitions that are needed for unit training.

This premise has two important implications. First, the benefits of flight simulators must be measured in terms of increased aviator proficiency rather than reduced training costs. Second, it will be necessary to establish the value of increased aviator proficiency in order to determine the return on the investment in flight simulators.

Potential Applications

A necessary first step in designing research to assess the training effectiveness of the AH1FS is to identify the full range of potential training applications in the unit-training context. The following paragraphs describe the potential applications that are apparent at this time. The research has been designed to assess the training effectiveness of the AH1FS for each of these applications.

Refresher Training

Every aviation-unit commander is responsible for the development and implementation of a unit refresher-training program. This program is designed to assist ARL3 (Aviator Readiness Level-3) aviators to regain their proficiency on the base tasks designated by the unit commander. Refresher training is mandatory for aviators returning to operational flying after having been prohibited or excused from flying duties for more than 180 days. Also, the unit commander has the option of requiring refresher training for aviators with fewer than 180 days of non-flight duties. It is estimated that between 15 and 25 AH-1 aviators in an air cavalry attack brigade will require refresher training each year, and that between five and 15 aircraft hours per aviator will be required to accomplish the refresher training.

Although flight simulators seem ideally suited to refresher training, there are no data with which to estimate the effectiveness of any Army flight simulator for refreshing Army aviators' flying skills. As a consequence, this research has been designed to determine in what way, and to what extent, the AH-1 flight simulator can be used to fulfill the refresher training requirements.

Sustainment Training

It is generally recognized that sustainment training is a potentially beneficial application of flight simulators. However, the manner in which flight simulators are used to sustain flying proficiency is greatly influenced by the Army's training policy. Under the current training concept, unit commanders are encouraged to develop training

scenarios for mission-support flights that will ensure that aviators practice as many tasks as possible during routine mission support flights.

If unit commanders adhere strictly to this policy, the practice performed during mission-support flights in the aircraft should be sufficient to sustain skills on many flying tasks. However, there are some tasks for which skills simply cannot be sustained during mission-support flight, regardless of the scenario adopted. One example is touchdown emergency procedures. Under current policy, unit aviators are prohibited from performing touchdown emergency procedures during training. Operation of weapons systems is another example of tasks for which skills cannot be sustained during mission-support flying. Sufficient practice on weapons systems is prevented by constraints such as limited supply of munitions for training and, for some units, limited access to suitable firing ranges.

The above considerations make it apparent that, if flight simulators are to be used effectively for sustaining skills, flight simulator training must focus only on the subset of tasks for which skills are not maintained during routine mission-support flights.

There is a great deal of anecdotal evidence that the amount of training required to sustain flying skills varies as a function of an aviator's prior flying experience and the aviator's aptitude. So, these factors have been taken into account in designing research to assess the benefits of using flight simulators to sustain the skills of unit aviators.

Enrichment Training

Enrichment training is another potential application of flight simulators in a unit-training context. As the term is used here, enrichment training refers to simulator training that accomplishes one or more of the following:

- increases the rate at which skills are acquired through aircraft training alone,
- increases the level of skill achievable through aircraft training alone,
- provides training on tasks that are not currently trained in the aircraft, and
- provides training on tasks that cannot be trained in the aircraft.

The type and amount of enrichment training an aviator needs is largely dependent upon the aviator's level of experience; so, the enrichment training needs of low-time aviators and of medium/high-time aviators are discussed separately.

Low-time aviators. It is widely recognized that aviators who have recently graduated from an Aircraft Qualification Course (AQC) lack the level of flying skills needed to fly safely and to perform effectively in combat. Although there are no empirical data that can be used to specify the type and extent of low-time aviators' skill deficiencies, the training practices of unit commanders leave no doubt that such skill deficiencies exist. For instance, some unit commanders require all new AQC graduates to complete the unit's refresher training program before being assigned a position in the unit. Furthermore, there is anecdotal evidence that aviators are not permitted to fly as Pilot in Command (PIC) until they have accumulated about 200 hours flying as copilot, and have demonstrated to the unit commander that they possess the necessary level of skill and judgment to assume the responsibilities of PIC.

Although most low-time aviators eventually acquire the necessary level of skill through aircraft training alone, it seems highly probable that the desired level of skill could be achieved much more quickly if a low-time aviator's normal flying activities were augmented with training in a flight simulator. As is discussed later, the proposed research has been designed to determine the extent to which flight-simulator training decreases the amount of time that a low-time aviator requires to achieve the skills necessary to assume the responsibility of PIC.

At this point, it should be mentioned that a fundamental objective of the enrichment training program is to aid low-time aviators in reaching the "autonomous phase" of learning for both procedural and psychomotor tasks. During this phase of skill learning, task performance becomes increasingly autonomous, less subject to cognitive control, and less subject to interference from other ongoing activities or environmental distractions. Once aviators have reached the autonomous phase of learning, flying tasks can be performed while new learning is in progress or while an individual is engaged in other perceptual and cognitive activities.

Medium- and high-time aviators. Enrichment training in a flight simulator also has considerable potential for increasing the combat skills of medium- and high-time aviators. Because of various constraints on training in the aircraft, even the most experienced aviators may lack the skill needed to perform effectively under some of the adverse conditions that almost certainly will be encountered in combat. Accordingly, as it is presently conceived, enrichment training for medium- and high-time aviators would be designed to accomplish the following:

- train aviators to perform selected flying tasks under adverse visibility conditions, such as darkness, fog, rain, snow, smoke, and dust;
- train aviators to perform selected flying tasks with night-vision goggles (NVGs) and mission-oriented protective posture (MOPP) gear;

- train aviators to perform effectively during periods of heavy cognitive and perceptual motor workload;
- train aviators to perform effectively under high affective loading (stress, fear);
- train aviators to recognize the limits of the aircraft's flight envelope;
- train aviators on the techniques of air-to-air combat, including how to fly near but not exceed the performance envelope of the aircraft;
- train aviators to perform evasive actions for the full range of enemy threat weapons, including: enemy aircraft, air defense missiles, and small arms fire; and
- train aviators to make valid judgments under varying levels of information uncertainty, cognitive complexity, time constraints, and stress.

With minor modifications of the AH-1 flight simulator, it may also be possible to design simulator training to increase aviators' tactical decision-making skills.

It is expected that most of the enrichment training for medium- and high-time aviators will take the form of complex mission scenarios.

Safety Enhancement Training

A third potential application of flight simulators is to provide training that is specifically designed to reduce the incidence of accidents. Although any training that serves to increase the flying skills of Army aviators will likely contribute to aviation safety, the flight simulator training proposed here will be designed specifically to reduce the incidence of specific types of aircraft accidents. The four types of accident reduction training that appear most promising are discussed below.

Accident scenario training. The first type, accident scenario training, involves the use of a flight simulator to reenact, as faithfully as possible, all the conditions and actions that have been shown to contribute (directly or indirectly) to a frequently occurring type of accident. In principle, the accident scenario training will teach aviators to recognize hazard cues and teach them to recover the aircraft safely when the accident-producing situation is encountered. Personnel from the U.S. Army Safety Center will be responsible for providing information about frequently occurring accidents and the factors that contribute to such accidents.

Flight envelope training. A second type of simulator training that may enhance safety is referred to here as flight envelope training.

Some aircraft accidents occur when an aviator deliberately or inadvertently flies an aircraft to the extremes of the flight envelope and is unable to control the aircraft in that situation. Safety considerations prevent IPs from exposing trainees to the handling qualities of the helicopter when flying near the extremes of its flight envelope. Consequently, the trainee may be unprepared to control the aircraft when such situations are encountered. It seems probable that this skill deficiency could be eliminated through training in a flight simulator. This type of training differs from advanced enrichment training in that it focuses only on the extremes that are known to contribute to frequently occurring accidents.

Extreme conditions training. A third type of safety enhancement training, extreme conditions training, is also driven by data on Army aircraft accidents. The objective is to identify the types of extreme environmental conditions that frequently contribute to aircraft accidents and to use the simulator to train aviators to maintain control of the aircraft when such situations cannot be avoided.

Aircrew judgment training. The final type of safety enhancement training, aircrew judgment training, is aimed at reducing Army aircraft accidents that are caused wholely or in part by by poor judgment. To accomplish such training, it will be necessary to simulate as closely as possible the conditions that contribute to accident-producing judgments. These conditions include, but are not necessarily limited to the following:

- information uncertainty,
- time constraints,
- cognitive complexity of judgment,
- stress,
- the flight problem, and/or
- the background problem.

Maintenance Test Pilot (MTP) Training

Although the training of MTPs does not constitute a major training burden, it is nevertheless a potential training application of flight simulators that should not be overlooked. Given the capability to program malfunctions and given adequate fidelity of the simulator's response characteristics, MTPs could acquire considerable knowledge in a flight simulator about malfunction detection and diagnosis.

RESEARCH PLAN

This section describes a plan of research that has been designed to provide data with which to assess the benefits and limitations of employing flight simulators to train field-unit aviators. Although this research was designed specifically to evaluate the AH1FS, the general approach is considered suitable for assessing the unit-training benefits and limitations of any Army flight simulator.

The task-flow diagram in Figure 7 shows the research tasks to be accomplished and shows the interrelationship among the tasks. Each of the tasks shown in Figure 7 is discussed below in the order in which they are to be accomplished.

Conduct Analytical Studies

This project will commence with two analytical studies. The product of the first study will be a training-task taxonomy; the product of the second study will be a listing of target training tasks and conditions.

Develop training-task taxonomy. An important part of this research is the development of a comprehensive training-task taxonomy. An acceptable taxonomy must list the full set of flying tasks that AH-1 aviators must be capable of performing, and the full range of conditions in which aviators must be capable of performing each task. The Aircrew Training Manual (ATM) task list represents a good point of departure, but cannot be used in its present form for two reasons. First, the ATM tasks differ greatly in their level of specificity; some tasks, such as Hovering Turn, are very specific; other tasks, such as Navigation by Dead Reckoning, are very general. Second, the ATM tasks are not mutually exclusive; that is, some ATM tasks are composites of several other ATM tasks.

The final product will be a task-by-condition matrix that shows, for each task, the conditions under which an AH-1 aviator may be required to perform that task. The training task taxonomy will be developed and evaluated by knowledgeable aviators and training experts. The training task taxonomy will be continuously refined until it is possible to define any training scenario by linking together task/condition combinations represented by cells in the matrix.

Identify target training tasks/conditions. The purpose of this analytical effort is to examine each cell in the task/condition matrix, and to identify the tasks/conditions for which flight simulator training is possible and probably beneficial. A thorough study of the design characteristics of the AH-1 flight simulator will be required to determine whether or not it is possible to simulate a given task/condition. When it is clear that a task/condition combination cannot be simulated, an attempt will be made to determine whether or not a low-cost design modification would make it possible to simulate the task/condition in question. If so, the simulator design modification will be recommended. If not, the task/condition will be eliminated from further consideration.

Each of the task/condition combinations that remain in the matrix will then be examined and a judgment made as to whether or not benefits would result from training that task in the AH-1 flight simulator. This analytic judgment will be made with respect to three target groups: aviators who require refresher training, low-time unit aviators, and medium- and high-time unit aviators.

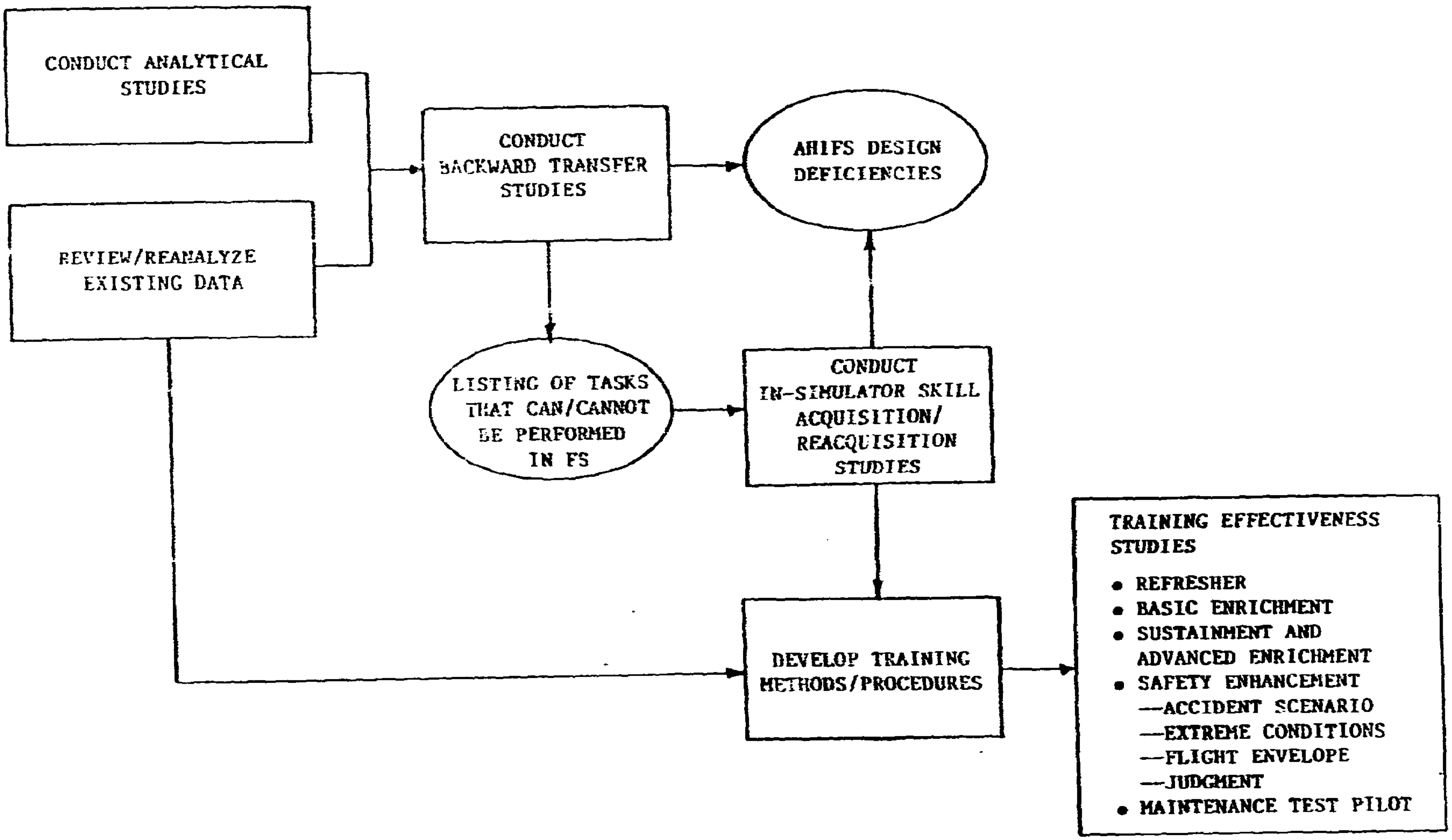

Figure 7. Task-flow diagram for simulator research plan.

The most critical and most difficult part of this effort will be to judge whether or not an adequate level of skill on a given task/condition can be acquired and sustained during routine mission-support flying. Obviously, simulator training makes no sense if aviators can easily acquire and sustain skill on a task during routine mission-support flying. In order to make such judgments, it will be necessary to conduct structured interviews with selected field-unit aviators and, possibly, selected DES personnel as well.

The tasks/conditions remaining in the matrix constitute the target tasks/conditions that are to be investigated during the empirical research.

Before proceeding, it should be stated that judgments about whether simulator training is possible and beneficial will be conservative. That is, no task/condition will be eliminated from the matrix if there is a reasonable chance that simulator training on that task/condition would be possible and beneficial.

Review/Reanalyze Existing Data

The objectives of this analytical effort are (a) to review and, when necessary, reanalyze existing data bearing on the use and benefits of flight simulator training, and (b) use the composite data to draw inferences about the design of the empirical research to be conducted subsequently.

Conduct Backward Transfer Studies

Research requirement. A "backward transfer study" is one that is designed to measure the degree to which actual flying skills transfer to a flight simulator. Only highly experienced aviators are used as subjects in a backward transfer study. The procedure is simple: an experienced aviator is placed in the flight simulator and instructed to perform the task of interest without the benefit of practice. If the aviator is able to perform the task to criterion, backward transfer is said to have occurred. The presence of backward transfer indicates that transfer from the flight simulator to the aircraft is likely to be positive, but provides no information with which to estimate the magnitude of the positive transfer.

More important for purposes of this research is the lack of a high degree of backward transfer. The inability of experienced aviators to perform a task to criterion in the flight simulator must be taken as evidence of a problem with either the design or the functioning of the flight simulator. Hence, the absence of a high degree of backward transfer signals the need for further study of the flight simulator's characteristics to determine the reasons for the low backward transfer. It is essential that such problems be resolved before proceeding to the more costly training effectiveness studies.

A variation of the backward transfer study is to train the experienced aviators in the simulator until their performance reaches an asymptotic level. This variation, of course, is appropriate only when there is a low degree of backward transfer. The nature of the learning curve in such cases provides useful diagnostic information. For instance, if the learning curve asymptotes below the criterion level of performance, it must be concluded that the flight simulator is either not providing the necessary cues or is incapable of processing control inputs correctly. Conversely, if the learning asymptotes at the criterion level after only a few practice trials, it can be concluded that the lack of high backward transfer is probably the result of minor differences between the stimuli and/or handling qualities of the simulator and those of the aircraft.

A second variation of the backward transfer study is to interview the subjects a second time after their first aircraft flight following simulator training. These interviews, like the earlier ones, would be aimed at identifying (a) differences between the handling qualities of the simulator and the aircraft, and (b) differences between the cues available in the simulator and the aircraft in flight.

Research objectives. The backward transfer-of-training studies have the following objectives:

- validate the results of the analytic study (can task be performed in the flight simulator?),
- validate simulator functioning,
- identify low-cost simulator design modifications that would increase the degree of backward transfer,
- establish upper limit of performance in the flight simulator, and
- determine the amount of flight simulator-unique learning that is required to perform to criterion level in the simulator.

Research approach. Twenty-five AH-1 instructor pilots (IPs) who have had no prior experience in the AH-1 flight simulator will serve as subjects in the study. Each subject will be required to perform each one of a selected sample of tasks/conditions. The sample of tasks/conditions will be selected to cover the full range of target tasks/conditions identified during the preceding analytic study. Each subject's performance will be measured on three consecutive trials. If performance has not reached criterion by the third trial, the subject will continue until performance reaches an asymptotic level.

After completing each task/condition, the subjects will be required to complete a rating form designed to identify the type and magnitude of differences between the aircraft and the flight simulator, with respect to the task/condition just performed. If deemed beneficial, the subjects will be required to complete similar rating forms after their first aircraft flight following simulator training.

The performance measures to be employed include: proficiency ratings by a trained observer, self ratings of proficiency by the IP who is serving as a subject in the experiment, and objective measures of selected flight parameters extracted from the flight simulator.

Research products. The specific products expected from the backward transfer studies include the following:

- a listing of the potentially trainable tasks/conditions;
- an indication of the best performance achievable in the flight simulator, by task and condition;
- a listing of the tasks/conditions that are not trainable in the flight simulator, and an indication of why these tasks/conditions are not trainable;
- a listing of low-cost simulator modifications that should increase the degree of backward transfer; and
- a listing of alternative methods or devices that would be more suitable for training tasks/conditions for which backward transfer is found to be low.

Resource requirements. Twenty-five experienced AH-1 IPs will be required to serve as subjects in this experiment. Another two AH-1 aviators who are thoroughly familiar with the AH-1 simulator will be required to operate the flight simulator and rate the subjects' performance. It is estimated that each subject will be required to spend approximately 5 hours in the flight simulator and that about 25 hours of flight simulator time will be required to develop the data collection procedures.

Conduct In-Simulator Skill Acquisition/Reacquisition Studies

Research requirement. The training effectiveness of any training device is largely determined by the manner in which it is used. This is particularly true for flight simulators. And yet, there is little empirical data that can be used to identify near-optimal training methods and procedures. Hence, before research is conducted to assess the training effectiveness of the AH-1 flight simulator, it is essential that research be conducted to assess the relative effectiveness of alternative simulator-training methods and procedures. This research must address the following training-program design issues and perhaps others as well:

- the order in which tasks are trained;
- the amount of training on each task/condition (fixed number of practice iterations vs. training to criterion);
- type of practice (repeated iterations on individual tasks vs. a training scenario);

- training schedule, including duration of flight simulator training and the interval between sustainment/enrichment training sessions;

- the type of feedback provided to the trainee; and

- the use of the instructional support features available on the AH-1 flight simulator.

Research objectives. The objectives of this research are to develop and evaluate the relative effectiveness of alternative training methods for each type of flight simulator training application, including:

- refresher training,
- basic enrichment training,
- advanced sustainment/enrichment training,
- safety enhancement training,
  - --accident scenario training,
  - --extreme conditions training,
  - --flight envelope training,
  - --judgment training, and
- maintenance test pilot training.

Research approach. A critical premise underlying this research is that valid decisions about training methods can be made from in-simulator performance data. Hence, the general research approach to be employed consists of examining in-simulator skill acquisition as a function of training method. The independent variables to be investigated include:

- training application (refresher, enrichment, etc.),
- training methods and procedures, and
- the sequence in which the tasks are trained.

The dependent variables for this research include:

- iterations to asymptotic performance,
- training time to asymptotic performance,
- highest level of skill achieved, and
- performance variability.

Research products. This research will yield the data needed to define a near-optimal training method for each simulator training application identified above.

Resource requirements. It is estimated that six separate studies will be conducted, and that each study will require a total of twelve AH-1 aviators to serve as subjects. The characteristics of the aviators required for the study are as follows:

- refresher training study--AH-1 qualified but not current;

- basic enrichment training--AH-1 qualified, current, and low-time;

- advanced sustainment/enrichment--AH-1 qualified, current, and medium-time;
- safety enhancement
  --accident scenario training--AH-1 qualified, current, and medium-time;
  --extreme conditions training--AH-1 qualified, current, and medium-time;
  --flight envelope training--AH-1 qualified, current, and medium-time;
  --judgment training--AH-1 qualified, current, and medium-time; and
- maintenance test pilot training--AH-1 qualified, current, and medium-time.

In addition to aviators to serve as subjects, two experienced IPs will be needed to operate the simulator and evaluate the subjects' performance.

It is estimated that from 300 to 600 hours of simulator time will be required to develop the research procedures and to conduct the research.

Develop Training Methods/Procedures

The composite results of the analytical studies, the backward transfer studies, and the in-simulator skill acquisition/reacquisition studies will be used to develop training methods/procedures for each of the following types of flight simulator training:

- refresher training,
- basic enrichment training,
- sustainment and advanced enrichment training,
- safety enhancement
  --accident scenario training,
  --extreme conditions training,
  --flight envelope training,
  --judgment training, and
- maintenance test pilot training.

The training methods and procedures will be developed by a team composed of experienced AH-1 aviators, psychologists, training technologists, and experts in simulator design.

Evaluate Refresher Training Program

Research requirement. Some portion of a unit commander's annual flight hour program is devoted to the use of AH-1 aircraft time for refresher training. The commander's guide to the aircrew training manual (FC-1-210) defines refresher training as training for aviators

"prohibited or excused from flying duties for more than 180 days" (p. 2-34). Anecdotal evidence suggests that between 5 and 15 AH-1 aircraft hours are required to "refresh" the skills of ARL3 aviators. It is possible that a significant portion of the refresher training currently being conducted in the AH-1 aircraft could be accomplished in the AH1FS. Thus, a requirement exists to determine in what way, and to what extent, the AH1FS can be used to fulfill these refresher training requirements.

Research objective. The objective of this research is to obtain data with which to evaluate the effectiveness of the AH1FS for accomplishing refresher training of ARL3 aviators.

Research approach. The research will utilize a modified version of the transfer-of-training paradigm. Thirty-six AH-1 aviators who have not flown for at least 180 days will be matched demographically and divided into three groups. One group of 12 aviators will receive refresher training in the AH-1 aircraft (aircraft training control group). A second group of 12 aviators will undergo 12 hours of mental rehearsal of all relevant tasks under the supervision of a trained AH-1 IP before being trained to criterion in the AH-1 aircraft (mental practice control group). The third group of 12 aviators will receive AH1FS training until proficient on all relevant tasks and, subsequently, will be trained to criterion in the aircraft (experimental group).

The effectiveness of the AH1FS for refresher training will be evaluated using the following performance measures:

- the number of AH-1 aircraft hours required for training,
- the number of iterations to criteria in the AH-1 aircraft (by task),
- the number of iterations per aircraft hour (collapsed across tasks),
- IP proficiency ratings in the aircraft (by task), and
- SIP checkride ratings in the aircraft (by task).

Research products. The specific products expected from the refresher training research include:

- the data with which to assess the feasibility and benefits of refresher training in the AH1FS, and
- a refresher training program of instruction.

Resource requirements. Thirty-six ARL3 AH-1 aviators will be required to conduct this research. Additional resource requirements depend on the site at which the research is conducted and the ability to incorporate the research into existing training programs.

Basic Enrichment Training

Research requirement. As emphasized earlier in this report, increased operational effectiveness is the ultimate criterion for evaluating the utility of the AH1FS for unit training. The assumption has been made that if the AH1FS can be used to increase the proficiency of the AH-1 aviators assigned to the unit, the AH1FS will have made a major contribution toward increasing operational effectiveness. A second assumption made here is that the training requirements for increasing the proficiency of low time aviators are markedly different from the training requirements for increasing the proficiency of medium- and high-time aviators. Thus, two different training programs--basic enrichment training and sustainment and advanced enrichment training--have been recommended as viable training programs for utilizing the AH1FS at the operational units.

Basic enrichment training focuses on skill enhancement for low-time aviators who have recently completed the AH-1 AQC. The primary goal of basic enrichment training is to decrease the amount of time required to develop the level of skill and confidence needed to assume the responsibilities of PIC. Unit commanders realize that the operational effectiveness of their unit depends, to some extent, on how quickly new aviators can develop and solidify their basic skills and assume mission responsibilities once held by vacating aviators.

Thus, a research requirement exists to evaluate the extent to which basic enrichment training in the AH1FS increases the proficiency and confidence of low-time AH-1 aviators.

Research objective. The objective of this research is to obtain data with which to assess the effectiveness of the AH1FS for increasing the level of flying skills and confidence of low-time AH-1 aviators.

Research approach. Forty-eight recent AH-1 AQC graduates will receive a modified commander's checkride upon arrival at the unit. The modified commander's checkride will include mission and tactical ATM tasks that the aviator will be required to perform routinely. Aviators will be assigned to one of four groups based on the results of the checkride by the unit IP. The assignment will be made to equate initial proficiency level of the four groups of aviators. Based on a coordinated effort with the unit commander and unit training personnel, each aviator will fly approximately 25 aircraft hours during each quarter (3 months) for a period of one year. One group of 12 aviators will receive no basic enrichment training in the AH1FS (control group). The other three groups of 12 aviators will receive 6, 12, and 18 hours, respectively, of basic enrichment training in the AH1FS each quarter for a period of one year. The simulator training is in addition to the 25 hours of aircraft training that aviators in all four groups will receive each quarter.

At the end of each quarter, each aviator will complete a modified commander's evaluation checkride. These data will be used to assess the relative level of proficiency of aviators as a function of amount of simulator training. In addition, peer evaluations and aviator's self-ratings will be collected. These data will provide additional insight into the competence and confidence of the aviators and will allow for meaningful analysis of the overall effectiveness of the basic enrichment training.

Research products. The specific products expected from the research on basic enrichment training include:

- data with which to plot the relationship between amount of basic enrichment training in the simulator and proficiency level,
- data to use in conjunction with cost data to define the most cost-effective amount of basic enrichment training, and
- a basic enrichment-training program of instruction.

Resource requirements. Forty-eight low-time AH-1 aviators will be required to conduct this research. Four experienced AH-1 IPs will be required to develop data collection procedures and to conduct the AH1FS training. About 2,000 AH1FS hours will be required to conduct the training and evaluations.

Sustainment and Advanced Enrichment Training

Research requirement. Experienced aviators require training to ensure that skills to perform relevant flight tasks are maintained and that these skills are not seriously degraded by environmental or situational constraints. In attempting to delineate the types of AH1FS training that would increase the operational readiness of experienced aviators, requirements for two types of training emerged.

First, great benefits would be realized if experienced aviators could use the AH1FS to maintain proficiency on tasks for which skills are not maintained during routine mission-support flying. Currently, AH-1 aviators must utilize aircraft time to practice some tasks. Should it be demonstrated that the AH1FS can be used for skill sustainment, valuable aircraft hours could be devoted to training tasks for which skills are deficient and aircraft training is the only viable option. It should be noted that there are four categories of tasks for which skills are not maintained during routine mission-support flying:

- tasks that can be trained in the aircraft but are not ordinarily performed during routine mission-support flying,
- tasks that cannot be trained easily in the aircraft (e.g., IMC flight),
- tasks that are not currently being trained in the aircraft (e.g., touchdown emergency maneuvers), and

- tasks that are more effectively trained in the AH1FS (e.g., gunnery tasks).

Taken together, these represent a formidable array of tasks for which skills could decay without sustainment training in the aircraft or the AH1FS.

The second type of AH1FS training that could be beneficial for experienced aviators is skill enrichment. In the basic enrichment training program discussed earlier, low-time aviators are provided with AH1FS training on all ATM tasks under daytime and nighttime conditions; basic enrichment training focuses on skill solidification, increased competency, and increased confidence for low-time aviators. For experienced aviators, it is possible to concentrate on a very similar task list, but increase the complexity of the tasks by requiring the aviators to perform the tasks under adverse conditions, such as the following:

- wearing night vision goggles,
- wearing mission oriented protective posture (MOPP) gear,
- visual obscurants (rain, snow, fog, smoke), and
- wind (gusts, wind shear).

Anecdotal evidence suggests that concern for safety prevents or severely limits the extent to which aviators are permitted to practice under these conditions. And yet, military doctrine suggests that, should a military engagement occur, it is highly probable that there would be a requirement to conduct military operations under low illumination levels, adverse weather, and/or in nuclear, biological, or chemical (NBC) conditions. Therefore, this type of enrichment training in flight simulators could clearly increase the operational readiness of the units.

For the most part, rotary wing training programs assume that by demonstrating skill proficiency on ATM tasks, the aviator will be effective when required to perform combinations of those tasks under wartime conditions. Although ARTEP training provides the aviator with valuable insight into the battlefield experience, ARTEP training focuses largely on coordination and cooperation among various battle elements. Because of safety constraints, it is difficult, if not impossible, to "load the aviator up" with multiple tasks requiring rapid decision making and effective time-sharing techniques. However, this type of training is feasible using the AH1FS. For this reason, it appears highly desirable to include in advanced enrichment training a set of mission scenarios that are designed to increase aviators' ability to perform effectively during periods of heavy cognitive and perceptual-motor workload.

In addition to the above, advanced enrichment training should include training in air-to-air combat and training in evasive actions for other threat weapons, including air defense weapons and small arms fire.

Taken together, these types of training for experienced aviators, subsumed under sustainment and advanced enrichment training, represent an attempt to formulate an effective training strategy for not only sustaining but also increasing proficiency, thereby improving the operational effectiveness of the units.

Research objectives. The specific objectives of the research on sustainment and advanced enrichment training are to obtain data with which to assess the effectiveness of the AH1FS for each of the following:

- facilitating skill sustainment on those tasks not performed during routine mission flying,
- facilitating skill acquisition and sustainment for a variety of ATM tasks under a variety of adverse conditions (NVG, MOPP gear, visual obscurants, wind),
- increasing proficiency under high workload conditions,
- increasing air-to-air combat proficiency,
- increasing proficiency in performing the full range of evasive actions, and
- increasing aviator judgment ability under a wide range of conditions.

Research approach. Forty-eight experienced AH-1 aviators will be divided into four groups. Assignment procedures will be developed to ensure that the four groups are matched in terms of initial proficiency level and flying experience. Scores on a commander's checkride, flight hours logged in the AH-1 aircraft, hours logged in other aircraft types, and perhaps other demographic variables will be used in assigning aviators to the four groups. One group of 12 aviators will perform their normal flight routine within the unit (control group). Each of the three other groups of 12 aviators will receive 6, 12, or 18 hours, respectively, of AH1FS training per quarter for a period of one year. The AH1FS training will include both sustainment training and advanced enrichment training. Based on a cooperative effort with unit commanders and unit training personnel, each aviator will fly approximately 25 hours per quarter and will be limited to the types of tasks they can perform.

At the end of each quarter, each aviator will receive a proficiency checkride (in an aircraft). Although this checkride will include as many tasks as possible, a checkride on some of the tasks/conditions trained in the AH1FS will probably not be possible without incurring an unacceptable level of risk. In addition to IP ratings, each aviator in the experimental groups will be asked to provide assessments of the effectiveness of the training programs. These types of data will be collected each quarter for a period of one year. At the end of one year, the data will be analyzed to determine (a) the effectiveness of the AH1FS for each type of training, and (b) the optimal number of hours

in the AH1FS to facilitate skill proficiency. Together, these data will provide the basis for an overall evaluation of the effectiveness of the AH1FS for training experienced aviators. .

Research products. The research products expected from the sustainment and advanced enrichment training research include:

- data with which to plot the relationship between proficiency level and amount of sustainment and advanced enrichment training,
- data to use in conjunction with cost data to specify the most cost-effective amount of sustainment and advanced enrichment training, and
- a sustainment and advanced enrichment training program of instruction.

Resource requirements. Forty-eight experienced AH-1 aviators will be required to conduct this research. Four experienced AH-1 IPs will be required to conduct the AH1FS training. About 2,000 AH1FS hours will be required to develop data collection procedures and to conduct the training and evaluations.

Safety Enhancement Training

This subsection describes research to evaluate the effectiveness of the AH1FS in conducting four different types of safety enhancement training.

Accident Scenario Training

Research requirement. Although some aircraft training is aimed specifically at countering accidents, aircraft training in potential accident-producing situations necessarily involves some risk of causing the very type of accident the training is designed to counter. This risk would be eliminated if Army aviators could acquire the necessary accident avoidance skills in a flight simulator rather than in an aircraft. In addition to risk reduction during training, it is altogether possible that aviators could acquire a higher level of accident avoidance skills in the flight simulator than in an aircraft. In a flight simulator, it is possible to expose the trainee to all events up to and including the crash itself. Such exposure, of course, is not possible in the aircraft.

Accident scenario training is one type of training that promises to reduce the incidence of frequently occurring accident types. As was stated earlier, accident scenario training involves the use of a flight simulator to re-enact, as faithfully as possible, all the conditions and actions that have been shown to contribute (directly or indirectly) to a frequently occurring type of accident.

The accident types to be investigated during this research will be selected with the assistance of personnel from the U. S. Army Safety Center. However, based upon the information presently available, it appears likely that the following accident types will be among the ones selected for study:

- brown-out by blowing dust,
- dynamic roll-over,
- loss of tail rotor effectiveness, and
- settling with power.

Descriptions of the above accident types can be found in TM 55-1520-210-10 and FM 1-51.

Research objective. The objective of this research is to assess the effectiveness of the AH-1 flight simulator for training aviators to avoid and/or recover from known accident-producing situations.

Research approach. The most valid data on the effectiveness of accident scenario training would come from a longitudinal study in which accident involvement of aviators who received the accident scenario training is compared with accident involvement of aviators who did not receive the training. However, because of the low incidence of accidents, a longitudinal study would require the training of large numbers of aviators and the monitoring of accident records for an extended period of time. For this reason, a longitudinal study is considered unfeasible at this time.

The research approach that appears most feasible is an in-simulator study in which the measure of training effectiveness is the degree to which simulator training under one set of conditions transfers to in-simulator performance under a different set of conditions. Two groups of 15 AH-1 aviators will be matched on selected demographic variables. One group of 15 AH-1 aviators, the experimental group, will first be tested and then trained on each accident type under one set of conditions. Following the training, the conditions for each accident type will be changed and the experimental group aviators will be retested on the same accident types but under different conditions. A second group of 15 of AH-1 aviators, the control group, will be pretested and posttested in the same manner as the experimental group aviators. The difference between the two groups is that, rather than simulator training, the control group will receive only academic instruction on the nature of the accident types and the techniques for avoiding them.

Two types of performance measures will be used: in-simulator recovery rates, and in-simulator proficiency ratings by experienced IP.

Research products. The research products expected from the accident scenario training include:

- data with which to assess the feasibility of accident scenario training, and
- an accident scenario training program of instruction.

It should be noted that the research proposed above will not provide the data needed to define the most cost-effective amount of simulator training. If the concept proves feasible (a substantial amount of in-simulator transfer is found), additional research will be required to obtain the data needed to define the most cost-effective amount of accident scenario training in the AH1FS.

Resource requirements. Thirty AH-1 aviators who are current in the AH-1 aircraft will be required to accomplish this research. It is estimated that a total of 200 simulator hours will be required to (a) develop the testing and training procedures, and (b) conduct the training and the evaluations. In addition, two experienced AH-1 IPs will be required to operate the flight simulator and to evaluate the performance of the experimental-group and control-group aviators.

Extreme Conditions Training

Research requirement. Because of a unit commander's concern for safety, most aircraft training is conducted when environmental conditions are optimal or near-optimal. Although aircraft training during adverse environmental conditions would increase aviators' combat capabilities, such training is certain to increase the incidence of training accidents. It seems reasonable to hypothesize that flight simulator training under adverse conditions would decrease accident likelihood, especially under combat conditions where frequent exposure to adverse conditions is to be expected.

Research objective. The objective of this research is to assess the effectiveness of the AH-1 flight simulator for training aviators to operate the aircraft in extreme environmental conditions.

Research approach. A conventional transfer-of-training paradigm would yield the most valid assessment of the effectiveness of the flight simulator for training aviators to operate effectively under extreme conditions. However, measuring performance in the aircraft under extreme conditions almost certainly will involve an unacceptably high accident risk. The next best option is an in-simulator transfer paradigm of the type described above in connection with accident scenario training.

Further analytic study is required to make final decisions about the type and range of extreme conditions that should be investigated and to define the task(s) to be trained under each set of extreme conditions. The development of a detailed research approach is not possible until this analytic study has been completed.

Research products. The research products expected from the research on extreme conditions training include:

- data with which to assess the feasibility of extreme conditions training, and
- an extreme conditions training program of instruction.

It should be noted that the research proposed above will not provide the data needed to define the most cost-effective amount of simulator training. If the concept proves feasible (a substantial amount of in-simulator transfer is found), additional research will be required to obtain the data needed to define the most cost-effective amount of extreme conditions training in the AH1FS.

Resource requirements. A reasonably precise estimate of the resource requirements is not possible until the extreme conditions to be investigated have been determined. For present purposes, it is estimated that the resource requirements for this study will be the same as those for the accident scenario training research; 30 AH-1 aviators, about 200 hours of AH-1 flight simulator time, and two experienced AH-1 IPs for the duration of data collection.

Flight Envelope Training

Research requirement. Safety considerations prevent IPs from exposing trainees to the handling qualities of the helicopter when flying near the extremes of the flight envelope. Consequently, aviators may be unprepared to control the aircraft when the situation requires them to fly at or near the extremes of the helicopter's flight envelope. If true, accident likelihood could be reduced by using the AH1FS to train aviators to operate at or near the limits of the AH-1 aircraft. The reduction in accident likelihood could be of critical importance in combat, where extreme maneuvers may be essential for survival. The intent is to search the accident files of the U.S. Army Safety Center for accidents that have resulted from aviator inability to control the aircraft at the extremes of the flight envelope. This type of accident prevention training would focus on these accidents.

Research objective. The objective of this research is to obtain data with which to evaluate the effectiveness of the AH1FS for training aviators to fly at or near the extremes of the AH-1 flight envelope.

Measuring performance in the aircraft while flying at the extremes of the aircraft's performance envelope almost certainly would involve an excessive degree of risk. Hence, it is unlikely that a conventional transfer-of-training paradigm could be used to measure the effectiveness of the simulator training. As was true for both flight scenario training and extreme conditions training, an in-simulator transfer paradigm probably represents the only feasible approach to assess the effectiveness of flight envelope training in the flight simulator.

Further analytic study is required to identify the specific objectives of the flight envelope training. The development of a detailed research approach is not possible until this analytic study has been completed.

Research products. The research products expected from the research on flight envelope training include:

- data with which to assess the feasibility of flight envelope training, and
- a flight envelope training program of instruction.

It should be noted that the research proposed above will not provide the data needed to define the most cost-effective amount of simulator training. If the concept proves feasible (a substantial amount of in-simulator transfer is found), additional research will be required to obtain the data needed to define the most cost-effective amount of flight envelope training in the AH1FS.

Resource requirements. A reasonably precise estimate of the resource requirements is not possible until the flight envelope training requirements have been defined and a detailed research design has been developed. For present purposes, it is estimated that the resource requirements for this study will be the same as those for the accident scenario training research: 30 AH-1 aviators, about 200 hours of AH-1 flight simulator time, and two experienced AH-1 IPs for the duration of the data collection.

Judgment Training

Research requirement. There is clear evidence that poor judgment is a frequent contributor to both civil and military aircraft accidents (Lindsey, Ricketson, Reeder, & Smith, 1983; Jensen & Benel, 1977), and there is growing evidence that judgment training has the potential for reducing the incidence of such accidents (Berlin, Gruber, Holmes, Jensen, Lau, Mills, & O'Kane, 1982; Brecke, 1982; Jensen & Benel, 1977). Preliminary study indicates that judgment training on some judgment-related accidents could best be conducted in a flight simulator.

Research objective. The objective of this research is to obtain data with which to evaluate the effectiveness of the AH1FS for providing training that reduces potentially accident-producing judgment errors.

Research approach. The judgment training discussed here differs from the judgment training discussed in connection with advanced enrichment training in that the present training will focus only on judgment errors that have been shown to be accident producing. Once such judgment errors have been identified by the U.S. Army Safety Center, simulator training to curtail the key judgment errors will be developed and administered to a group of 15 qualified AH-1 aviators

(experimental group). An equivalent amount of academic instruction on the key decision errors will be administered to a demographically matched group of 15 AH-1 aviators (control group). Both the experimental group aviators and the control group aviators will be pretested and posttested in the simulator on flight scenarios that require judgments of the type under investigation. The two groups will be compared in terms of the frequency with which the correct judgments are made and, if appropriate, the time required to make the judgment.

Research products. The research products expected from the research on judgment training include:

- data with which to assess the feasibility of judgment training, and
- a judgment training program of instruction.

It should be noted that the research proposed above will not provide the data needed to define the most cost-effective amount of simulator training. If the concept proves feasible (a substantial amount of in-simulator transfer is found), additional research will be required to obtain the data needed to define the most cost-effective amount of judgment training in the AH1FS.

Resource requirements. The resource requirements are the same as those estimated for the extreme conditions training study.

Maintenance Test Pilot Training

Research requirement. Maintenance Test Pilots (MTPs) ordinarily become qualified by completing a course of instruction at the United States Army Aviation Logistics School (USAALS). Aviators may also receive MTP qualification by successfully completing an MTP equivalency examination administered by a USAALS Maintenance Test Flight Evaluator (MTFE). In either case, MTPs must learn to perform a variety of inflight maneuvers to assess the functioning of the aircraft and to correctly diagnose malfunctions when they are present. Like other unit aviators, MTPs have continuation training requirements they must fulfill (see FM 55-44). Many of the maneuvers that MTPs must perform during training and during maintenance check flights are violent and potentially hazardous.

Initial training and continuation training of MTPs is a potentially beneficial application of the AH1FS. However, the benefit of such training will depend upon the extent to which aircraft malfunctions can be programmed and the fidelity of the simulator's response to the programmed malfunctions. Research to assess the benefits of MTP training in the AH1FS will be conducted if the preliminary research shows that a sufficient number of malfunctions can be programmed and the simulator's response to the malfunctions is acceptable.

Research objective. The objective of this research is to assess the effectiveness of the AH1FS for training MTPs.

Research approach. A traditional transfer-of-training paradigm will be employed to assess the training effectiveness of the AH1FS for MTP training. One group of ten medium-time AH-1 aviators--the experimental group--will receive training in the AH1FS and then will be trained to criterion in the aircraft. A matched group of ten AH-1 aviators--the control group--will receive no training before being trained to criterion in the aircraft. The effectiveness of the simulator training will be assessed by comparing the two groups in terms of (a) the flight hours required to reach criterion in the aircraft, and (b) the proficiency ratings received on the final checkride.

Research products. The research products expected from the research on MTP training include:

- data with which to assess the feasibility of MTP training, and
- an MTP training program of instruction.

It should be noted that the research proposed above will not provide the data needed to define the most cost-effective amount of simulator training. If the concept proves feasible (a substantial amount of in-simulator transfer is found), additional research will be required to obtain the data needed to define the most cost-effective amount of MTP training in the AH1FS.

Resource requirements. Twenty qualified, medium-time aviators will be required to serve as subjects in this research. Two qualified MTFEs will be required to conduct the training in the AH1FS. The aircraft training and in-aircraft checkrides will be conducted in the same manner and by the same personnel as are used to train other MTPs.

AN ASSESSMENT OF THE EFFECTIVENESS OF TRAINING HELICOPTER INITIAL ENTRY STUDENTS IN SIMULATORS

INTRODUCTION

The research described in this subsection--Training Helicopter Initial Entry Students in Simulators (THIESIS)--is the only research discussed in Section III that is specifically aimed at the use and benefits of flight simulators for institutional training.

Background

Students entering the Army's IERW course learn their basic contact flying skills in the TH-55 aircraft--a small two-place helicopter the Army uses exclusively for training. After 50 hours of in-flight training in the TH-55, IERW students receive 125 hours of training in the UH-1H aircraft. To achieve instrument qualification, students must

complete 40 hours of instruction in the UH-1 flight simulator. After becoming qualified in the UH-1 aircraft, students may join an operational unit as a UH-1 aviator or enter qualification training in another aircraft type.

There is a clear and pressing need to consider alternatives to training basic flight skills in the TH-55 helicopter. The reasons for this need are explained below.

Cost/availability of training aircraft. The TH-55 is the only helicopter in the Army's inventory that requires high octane aviation fuel. In the event of a major fuel shortage, high octane fuel could become costly enough or scarce enough to disrupt the Army's IERW training program. Furthermore, maintaining a separate fleet of aviation fuel trucks and an aviation fuel contract is bothersome and expensive.

A more important concern is the impending end of the useful life of the TH-55. At present, no new TH-55 aircraft are being acquired to replace those in the aging fleet. A phase-out of the TH-55 would require the Army to select from among three training options: the acquisition of a new training aircraft to replace the TH-55, the conduct of primary flight training in an aircraft that is now in the Army inventory, or training helicopter initial entry students in simulators (THIESIS).

It seems unlikely that a decision will be made to purchase a new training helicopter. The Department of Defense has resisted proposals to develop and produce aircraft that are to be used solely for training. Furthermore, the Army has a strong desire to channel all available resources into operational equipment (Roscoe, 1980).

The replacement of training in the TH-55 with training in an operational helicopter is not a promising option because most operational Army helicopters are far more costly and consume considerably more fuel than the TH-55 (Grice & Morresette, 1982). Based upon initial cost and fuel consumption alone, it appears that the OH-58 is the only helicopter in the Army inventory that is even marginally suitable for use in conducting primary training.

Availability of other training resources. Because of limited training resources at Fort Rucker, the Army is unable to accommodate a large and sudden surge in the training load. During the mobilization of Army aviation for the Vietnam War, IERW graduates exceeded 5,000 per year. During this period, primary training in the TH-55 was conducted at Fort Wolters, Texas; only the advanced phases of IERW were conducted at Fort Rucker. When the Army phased down pilot training, all IERW training was consolidated at Fort Rucker, and the number of IERW graduates was reduced to fewer than 1,000 per year. The current IERW training load--about 2,000 students per year--severely taxes the usable airspace and physical facilities at the USAAVNC. In the event of another major mobilization, USAAVNC would be hard pressed to increase

the number of graduates to that of the Vietnam era without exceeding the capacity of existing airspace, stagefields, and other physical facilities at Fort Rucker. The reactivation of Fort Wolters is a feasible option, but a very costly one. It is possible that a more cost-effective option is to increase the training capability of Fort Rucker by increasing the amount of training that is conducted in flight simulators.

THIESIS feasibility study. The accomplishment of THIESIS research is complicated by the lack of a UH1FS equipped with a visual system. Before recommending the development of such a device for use in conducting comprehensive THIESIS research, it was deemed essential to conduct a preliminary study to evaluate the feasibility of the THIESIS concept. Such a study was recently completed at the Aviation Center. The THIESIS training was conducted in an AH1FS: a highly complex flight simulator that is equipped with a motion platform and a camera-modelboard visual system. The loading and balance of the AH1FS were adjusted such that the handling qualities of the AH1FS were as similar as possible to those of the UH-1 aircraft.

A group of ten student aviators were trained on basic flight tasks in the AH-1 simulator (experimental group). A matched group of ten student aviators received conventional training in the TH-55 aircraft (control group). Once the Primary Phase of IERW training had been completed, members of both the experimental group and the control group progressed through the same training sequence throughout the remainder of IERW training, which is conducted in the UH-1 aircraft. Data on academic grades, flight grades, flight hours, and setbacks were recorded for both groups throughout training. In addition, questionnaire data were collected from both students and IPs at critical points throughout training.

Only two students failed to complete the IERW training program satisfactorily. One member of the experimental group voluntarily withdrew from the program, and one member of the control group was involuntarily removed from the program due to lack of satisfactory progress. Although data analyses are still underway, it is clear that receiving primary training in the AH1FS did not significantly handicap members of the experimental group during the stages of IERW training that follow the Primary Phase. The few problems that the experimental group subjects encountered in transitioning from the simulator to the aircraft appear to be due to (a) differences in the handling qualities of the AH1FS and the UH-1 aircraft, and (b) shortcomings in the visual system. Both problems manifest themselves in poor initial performance on hovering tasks. These problems should not be encountered if a UH1FS equipped with a suitable visual system was used for THIESIS training.

Although detailed conclusions cannot be drawn until the data analyses have been completed, it is clear that the outcome of the feasibility study is sufficiently promising to justify further research in this important area.

Development of UH-1 training-research simulator. In order to proceed further with the THIESIS research, it is necessary to develop a UH-1 training research simulator. A research simulator suitable for this research must be equipped with a visual system and must have reasonably high fidelity handling qualities throughout the range of the flight envelope (UH-1 aircraft) typically encountered in performing the tasks taught during the Primary Phase of IERW training. The Army has recently contracted with personnel from the University of Alabama to design and develop a UH-1 training-research simulator that will be used to conduct further THIESIS research and perhaps other research as well. An existing Singer-Link 2B-24 UH1FS is being equipped with a Digital Image Generator (DIG) visual system (front and side window) and improved equations of motion.

Research Objectives

A three-phase line of research is envisioned. The objectives of each of the three phases are listed below:

- Phase I objectives (Transfer Study)
  --Evaluate cost effectiveness of using a UH1FS equipped with a visual display for Primary Phase training
  --Determine training transfer functions to UH-1 aircraft
  --Develop optimal THIESIS program of instruction from transfer data
  --Determine the contribution of platform motion to training effectiveness
- Phase II objectives (Integration Study)
  --Determine the optimum integration of simulator and helicopter training to complete the Primary Phase training objectives
  --Evaluate the TH-55 and UH-1 helicopters for integration with a visual simulator for Primary Phase training
  --Evaluate visual display technologies for cost and training effectiveness
- Phase III objectives (Complexity Study)
  --Determine the relationship between simulator complexity (visual system, motion system, cockpit displays/controls, and handling qualities) and Primary Phase training effectiveness
  --Determine the most cost-effective level of complexity for each simulator design parameter

RESEARCH APPROACH

Detailed plans for the THIESIS research cannot be formulated until the UH-1 training-research simulator has been designed, delivered, and evaluated and preliminary research has been completed. Consequently, it is possible to describe only the general research approaches to be employed during each phase of the research at this time.

Phase I: Transfer Study

A series of conventional transfer-of-training experiments will be conducted using Primary Phase students as subjects. Independent variables to be investigated include at least the following:

- tasks trained in the simulator,
- amount of simulator training received (training time and number of practice iterations),
- scene content of visual display system, and
- simulator instructional method/procedures.

All experiments will employ one or more control groups that receive training different from the simulator-trained experimental group(s). At least one control group will receive no simulator training whatsoever. Following the completion of Primary Phase training, subjects in all groups will be trained to criterion in the UH-1H aircraft. The same training methods and procedures will be used to train all subjects in the UH-1 aircraft.

The dependent variables will include performance measures and ratings in both the simulator (experimental groups) and the aircraft (experimental and control groups). Although a complete listing of dependent variables cannot be formulated at this time, it seems certain that the final list will include at least the following:

- practice time and iterations to criterion (by task),
- task ratings by IPs,
- daily grades by IPs,
- checkride scores, and
- measures of selected flight parameters (simulator only).

Phase II: Integration Study

The fundamental premise underlying the Phase II research is that interspersing simulator training and aircraft training will result in greater training effectiveness than completing all simulator training prior to exposing students to the aircraft for the first time. To fully assess the merits of this concept, it is necessary to determine the relationship between training cost (total cost of training to a prescribed level of proficiency in the UH-1 aircraft) and four independent variables: training mode (TH-55 aircraft, UH1FS, and UH-1 aircraft), amount of training for each mode, tasks trained with each mode, and the sequence of training by mode (the manner in which the modes are interspersed). It is clear that is would be excessively costly to employ a complete factorial design with four variables and several levels of each variable. However, a suitable alternative design has not yet been formulated. It is possible that a design based on response-surface methodology will prove feasible. Otherwise, it will be

necessary to address this issue through a series of analytical and empirical studies that may not provide the data needed to define the single, most cost-effective mix of training modes.

Phase III: Complexity Study

The Phase III research assumes the development of the capability to vary the complexity (or fidelity) of selected simulator design parameters. It is not possible to formulate a meaningful approach for Phase III research until detailed information is available on the capability to vary complexity, specifically, the parameters whose complexity can be varied and the extent to which the complexity of each parameter can be varied.

RESEARCH PRODUCTS

The products expected from the THIESIS research are listed below by research phase:

- Phase I:
  --data describing transfer of training functions for transfer from the UH1FS to UH-1 aircraft,
  --conclusions about the training effectiveness of motion, and
  --conclusions about the training effectiveness of computer graphics visual system.
- Phase II:
  --data with which to define optimal integration of simulator and aircraft training for Primary Phase training,
  --recommendation of most training/cost-effective visual display technology, and
  --recommendation of most training/cost-effective computer technolcgy.
- Phase III:
  --data with which to define the most cost/training-effective level of complexity for simulator design parameters investigated,
  --recommendation of optimal hardware configuration for low-cost, high-reliability THIESIS training, and
  --a program of instruction for Primary Phase training.

RESOURCE REQUIREMENTS

As was stated earlier, further progress on the THIESIS research is not possible until a UH-1 training research simulator is available. Any attempt to specify other resource requirements would be premature until the precise capabilities of the training research simulator are known and preliminary research has been completed. Only then will it be possible to develop detailed research designs, which, in turn, dictate the resources required to accomplish the THIESIS research.

INVESTIGATING THE FEASIBILITY OF USING VISUAL FLIGHT SIMULATORS FOR NIGHT VISION GOGGLE TRAINING

INTRODUCTION

The purpose of the research discussed in this subsection is to assess the feasibility of using a UH60FS for night vision goggle (NVG) training. Although NVG training in simulators is an important topic for the AH1FS research discussed in the previous subsection, the Army's need for data with which to assess the UH60FS's utility for NVG training is so pressing that it cannot await the completion of the AH1FS research, as outlined in the previous subsection. Hence, it is recommended that the following research be initiated as soon as possible even though some duplication of effort may result from this strategy.

Background

During the past two decades, there has been a major re-evaluation of traditional military strategies involving Army aviation. Specifically, recent military experience indicates that technological advances in aircraft detection and ground-to-air weaponry requires Army aviators to (a) employ low-altitude tactics, including NOE flight, as an integral part of their offensive and defensive strategies, and (b) expand their operational capabilities to include nighttime and adverse weather conditions. The combination of these two requirements--the performance of low-altitude tactics under low levels of illumination--may represent the greatest challenge to face Army aviation in its history.

The ability of Army aviators to perform terrain flight maneuvers and to navigate in unfamiliar environments at night using unaided scotopic vision is limited by the availability of ambient light. Without sufficient ambient light, the aviator simply cannot see the terrain clearly enough to fly safely or to navigate effectively. For more than a decade, the Department of the Army has sponsored research and development (R&D) aimed at producing a night vision device that facilitates the performance of terrain flight tactics under low levels of illumination.

The R&D effort began during the latter part of the Vietnam war when it became obvious that Army aviators must be capable of performing terrain-flight tactics during the day and at night in order to survive mid-intensity warfare. Based on a recommendation from a Modern Army Selected System Test, Evaluation, and Review (MASSTER), an IPR committee directed that a low-cost night vision goggle (NVG) device, originally developed for use by ground personnel (Johnson, Tipton, Newman, Wood, & Intano, 1972), be adopted as an interim solution to terrain flight under low levels of illumination. Thus, the Army Navy/Pilot Visual System (AN/PVS-5) NVG was procured and a Required Operational Capability (ROC) was issued without formal developmental testing or operational testing.

The standard AN/PVS-5 NVG is a binocular device with unity magnification. It is approximately 6½ inches square, weighs 28 ounces, and provides a 40° field-of-view with a visual acuity of approximately 20/50. The device contains two electro-optical systems designed to perform optimally under low levels of illumination. Each electro-optical system contains an image intensifier tube that increases the number of ambient light particles and utilizes fiber optics to project a visual image onto a green phosphorous plate.

The IPR committee accepted the AN/PVS-5 NVG as an "interim solution" to the requirement for a night vision device to facilitate performance of Army aviators. The committee members knew from the outset that the AN/PVS-5 NVG was not ideally designed for use in an aircraft cockpit. Therefore, it was not surprising that subsequent research and experience demonstrated that the standard AN/PVS-5 NVG is only a marginally acceptable night vision device (see Gunning, 1983). However, the problems revealed by the research and experience have guided the modifications of the standard AN/PVS-5 (McLean, 1982) as well as the design of the newest night vision device, the Aviator Night Vision Image System (ANVIS) (Richardson & Crew, 1981).

Need/Problem

Pursuant to the instructions of the IPR Committee ROC, NVG training requirements were established and detailed in the ATM for each Army aircraft. Each ATM specifies the prerequisites for NVG training, as well as the academic and flight training requirements for NVG qualification training, NVG continuation training, and NVG refresher training. For example, to become NVG qualified, an aviator must:

- receive 10.5 hours of academic instruction in night (unaided) flight and NVG flight procedures,
- demonstrate proficiency in the performance of all ATM tasks (except for the 5,000 series tasks) during night (unaided) flight,
- receive 1.5 hours of cockpit blackout training prior to beginning NVG flight training, and
- receive between 8.5 and 13.5 hours of NVG flight training prior to demonstrating proficiency to an NVG qualified IP.

The ATM requirements for NVG qualification training are representative of the training requirements for NVG continuation training and NVG refresher training. That is, except for 1.5 hours of cockpit blackout training, all flight training is conducted in the aircraft.

Given the safety problems associated with using night vision devices during rotary-wing flight, it is probable that accident risks can be reduced by accomplishing some portion of NVG training in visual flight simulators, prior to NVG training in the aircraft. Furthermore,

if the NVG flight training currently being conducted in the aircraft can be augmented by training in visual flight simulators, there is a potential for enormous savings in manpower, aircraft time, and other resource requirements.

Research Objectives

The specific objectives of this research are as follows:

- to identify the NVG tasks that can be trained in a visual flight simulator,
- to develop a POI to be used in training NVG tasks in a visual flight simulator, and
- to determine the feasibility of NVG training in visual flight simulators.

Research Approach

A two-phase research approach is recommended. The first phase is an in-simulator skill acquisition study that addresses the feasibility question in a short period of time and with a relatively small amount of resources. This research design provides information about the NVG skill acquisition of 10 UH-60 Aviation Qualification Course (AQC) graduates undergoing NVG training in the UH60FS. Each subject will be trained on relevant NVG tasks during five three-hour simulator sessions. By comparing each subject's performance on each ATM task during the fifth simulator session with his/her performance on the same ATM task during the first simulator session, it is possible to assess the extent to which performance of NVG tasks in the simulator improves with simulator training. Tasks for which in-simulator skill acquisition is exhibited will be retained for further study during the second phase.

The second phase is a traditional transfer-of-training study that addresses the most important questions associated with NVG training in visual flight simulators. This study is designed to allow detailed comparisons of performance and skill acquisition of (a) a group of subjects trained to NVG qualification in the UH-60 aircraft (control group), and (b) a group of subjects who receive NVG training in the UH60FS prior to NVG qualification training in the UH-60 aircraft (experimental group). The results of this research design can be used to (a) assess the rate of skill acquisition during training in a visual flight simulator, (b) identify the transfer-of-training from the simulator to the aircraft by task, and (c) estimate the total savings in aircraft time, IP time, and other resources that can be realized from training in visual flight simulators. This design is resource intensive and requires extensive support by various Fort Rucker agencies.

Research Products

The products that can be expected from this research include: (a) a listing of the tasks for which NVG training is feasible and beneficial, (b) data with which to assess the cost-effectiveness of NVG training in a flight simulator, (c) a program of instruction that can be used in either an institutional or unit-training setting, and (d) 36 aviators that are partially trained (16) or fully trained (20) on NVG flight in the UH-60 aircraft.

Resource Requirements

The development of a program of instruction to use in conducting the research will require six UH-60 AQC graduates to serve as subjects, one IP, about 50 UH-60 aircraft hours, and about 50 UH60FS hours.

The first phase of the UH60FS NVG research will require 10 UH-60 AQC graduates to serve as subjects, five UH-60 IPs, and about 220 hours of UH60FS time. Each subject will be required to devote about 40 hours to orientation, academic training, and flight simulator training over a ten-day period.

The second phase of the research will require 20 UH-60 AQC graduates to serve as subjects, six IPs, about 360 UH-60 aircraft hours, and about 160 UH60FS hours. Each subject will be required to devote about 60 hours to orientation, academic training, aircraft training, and flight simulator training over a 15-day period.

It should be noted that about one-third of the academic instruction and flight hours required to conduct this research is devoted to training on unaided night flight. The requirement for this time would be eliminated if the research could be conducted at a field unit using pilots who are already qualified on unaided night flight.

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APPENDIX A

FLYING TASK LIST BY HELICOPTER TYPE

ATM #	TASK TITLE	UH-1	AH-1	OH-58	CH-47	UH-60	AH-64	AHIP SCOUT	TH-55
1001	Plan a VFR flight	X	X	X	X	X	X	X	X
1002	Plan an IFR flight	X	X	X	X	X	X	X	
1003	Prepare DD Form 365F (Weight and Balance)	X	X	X	X	X	X	X	
1004	Use Performance Charts	X	X	X	X	X	X	X	X
1005	Prepare Performance Planning Card (PPC)	X	X	X	X	X	X	X	X
1501	Perform preflight inspection	X	X	X	X	X	X	X	X
1502	Perform before takeoff checks	X	X	X	X	X	X	X	X
1506	Perform ground taxi				X	X	X		
2001	Perform takeoff to a hover	X	X	X	X	X	X	X	X
2002	Perform hover power check	X	X	X	X	X	X	X	X
2003	Perform hovering turns	X	X	X	X	X	X	X	X
2004	Perform hovering flight	X	X	X	X	X	X	X	X
2005	Perform landing from a hover	X	X	X	X	X	X	X	X
2501	Perform normal takeoff	X	X	X	X	X	X	X	X
2502	Perform simulated maximum performance takeoff	X	X	X	X	X	X	X	X
2503	Perform rolling takeoff				X	X	X		
3001	Perform straight-and-level flight	X	X	X	X	X	X	X	X
3002	Perform (normal) climbs and descents	X	X	X	X	X	X	X	X
3003	Perform turns	X	X	X	X	X	X	X	X
3004	Perform deceleration/ acceleration	X	X	X	X	X	X	X	X
3005	Perform traffic pattern flight	X	X	X	X	X	X	X	X
3006	Perform fuel management procedures	X	X	X	X	X	X	X	
3007	Perform high-speed flight		X				X		
3010	Perform navigation by pilotage and dead reckoning	X	X	X	X	X	X	X	X
3011	Perform doppler navigation		X		X	X	X	X	

ATM #	TASK TITLE	UH-1	AH-1	OH-58	CH-47	UH-60	AH-64	AHIP SCOUT	TH-55
3025	Perform flight with AFCS servo off				X	X	X		
3102	Perform positive and negative "G" flight						X		
3501	Perform before landing checks	X	X	X	X	X	X	X	X
3502	Perform normal approach	X	X	X	X	X	X	X	X
3504	Perform shallow approach	X	X	X	X	X	X	X	X
3505	Perform steep approach	X	X	X	X	X	X	X	X
3506	Perform go-around	X	X	X	X	X	X	X	X
3507	Perform roll-on landing				X	X	X		
3510	Perform confined area operation	X	X	X	X	X	X	X	X
3511	Perform slope operation	X	X	X	X	X	X	X	X
3512	Perform pinnacle/ridgeline operation	X	X	X	X	X	X	X	X
4001	Perform hovering autorotation	X	X	X				X	X
4002	Perform standard autorotation	X	X	X	X	X	X	X	X
4003	Perform standard auto-rotation with 180° turn	X	X	X		X*		X	
4004	Perform low-level autorotation	X	X	X		X*		X	
4005	Perform simulated hydraulic system malfunction	X	X*	X	X*	X*	X**	X	
4006	Perform simulated antitorque malfunction	X	X	X		X*	X	X	
4007	Perform manual throttle operation (emergency governor)	X	X						
4008	Perform simulated engine failure at altitude	X	X	X	X	X	X	X	X
4009	Perform simulated engine failure at a hover	X	X	X	X	X	X	X	X
4010	Perform emergency procedures for actual or simulated NVG failure	X	X	X	X	X		X	
4018	Perform low-level, high-speed autorotation		X				X		
4019	Perform running landing	X	X	X				X	X

*Task practiced in the simulator only.
**Simulator requirements not yet finalized.

ATM #	TASK TITLE	UH-1	AH-1	OH-58	CH-47	UH-60	AH-64	AHIP SCOUT	TH-55
4020	Perform simulated engine failure, high speed at altitude		X				X		
4021	Perform flight with SCAS/ SAS/AFCS off		X		X	X	X	X	
4022	Perform Electronic Control Unit (ECU) lockout operation					X	X		
4023	Perform single engine failure with roll-on landing				X	X	X		
4024	Perform emergency procedures for stabilator malfunction					X	X		
4026	Perform emergency procedures for emergency landing	X	X	X	X	X	X	X	X
4027	Perform emergency procedures for flight control system malfunction	X	X	X	X	X	X	X	X
4028	Perform emergency procedures for engine system malfunction	X	X	X	X	X	X	X	X
4029	Perform emergency procedures for fires	X*	X*		X*	X*	X**	X**	
4030	Perform emergency procedures for fuel system malfunctions	X*	X*	X	X*	X*	X**	X**	X
4031	Perform emergency procedures for electrical system malfunction	X	X	X	X	X	X	X	X
4032	Perform emergency procedures for rotor, transmission, and drive train malfunctions	X*	X*		X*	X*	X**	X**	
4035	Perform antitorque failure at a hover			X			X		X
4134	Perform emergency descent						X		
4501	Perform instrument takeoff	X	X*		X	X	X	X**	
4503	Perform radio navigation	X	X	X	X	X	X	X	
4504	Perform holding procedure	X	X	X	X	X	X	X	
4505	Perform unusual attitude recovery	X	X	X	X	X	X	X	X
4506	Perform radio communication procedures	X	X	X	X	X	X	X	X
4508	Perform NAVAID approach	X	X	X	X	X	X	X	
4509	Perform ground controlled approach	X	X	X	X	X	X	X	

*Task practiced in the simulator only.
**Simulator requirements not yet finalized.

ATM #	TASK TITLE	UH-1	AH-1	OH-58	CH-47	UH-60	AH-64	AHIP SCOUT	TH-55
4512	Perform tactical instrument takeoff	X	X	X	X	X	X	X	
4513	Perform tactical instrument approach	X	X	X	X	X	X	X	
4517	Perform Command Instrument System (CIS) operations				X				
5001	Perform terrain flight mission planning	X	X	X	X	X	X	X	
5002	Perform terrain flight navigation	X	X	X	X	X	X	X	
5003	Perform low-level flight	X	X	X	X	X	X	X	
5004	Perform contour flight	X	X	X	X	X	X	X	
5005	Perform nap-of-the-earth (NOE) flight	X	X	X	X	X	X	X	
5006	Perform masking/unmasking	X	X	X	X	X	X	X	
5007	Perform NOE deceleration	X	X	X	X	X	X	X	
5008	Perform out-of-ground-effect (OGE) hover check	X	X	X	X	X	X	X	
5009	Perform terrain flight takeoff	X	X	X	X	X	X	X	
5010	Perform terrain flight approach	X	X	X	X	X	X	X	
5011	Perform FM radio homing	X	X	X	X	X	X	X	
5012	Perform visual glideslope approach and landing	X	X	X	X	X	X	X	
5014	Perform tactical instrument flight planning	X	X	X	X	X	X	X	
5018	Perform evasive maneuvers	X	X	X	X	X	X	X	
5019	Operate radar warning receiver AN/APR 39	X	X	X	X	X	X	X	
5020	Perform ski landing	X	X	X				X	
5021	Perform preflight inspection of ski installation	X	X	X				X	
5022	Perform hover/taxi over snow	X	X	X	X	X	X	X	
5024	Perform techniques of movement		X	X			X	X	
5025	Identify US/allied and threat weapons and aircraft	X	X	X	X	X	X	X	
5027	Perform laser beacon operations						X		
5029	Perform water operations				X				

ATM #	TASK TITLE	UH-1	AH-1	OH-58	CH-47	UH-60	AH-64	AHIP SCOUT	TH-55
5030	Perform circling approach from terrain flight	X	X	X	X	X	X	X	
5033	Negotiate wire obstacles	X	X	X	X	X	X	X	
5035	Perform recognition of hazards to terrain flight	X	X	X	X	X	X	X	
5036	Perform as a crew member (cockpit teamwork)	X	X	X	X	X	X	X	
5100	Operate communications equipment	X	X	X	X	X	X	X	X
5106	Operate chaff dispenser	X	X	X	X	X	X	X	
6001	Perform multi-aircraft operations (formation flight)	X			X	X			
6011	Perform external load operations	X			X	X			
6016	Perform target handoff to attack helicopters		X	X			X	X	
6044	Supervise installation and loading of weapons		X				X	X	
6045	Preflight aircraft weapon systems		X				X	X	
6046	Operate Heads-Up Display (HUD)		X						
6047	Operate Rocket Management System (RMS)		X				X		
6049	Perform weapons cockpit procedures		X				X	X	
6050	Operate M28/M197 turret system		X						
6051	Operate M28/M197 turret system using helmet sight system		X						
6054	Operate reflex sight M73/M60		X						
6055	Operate 2.75 inch FFAR rocket launcher		X				X		
6056	Operate M35 (20mm) weapon system		X						
6057	Operate Telescopic Sighting Unit (TSU)		X						
6058	Operate TOW missile system		X						
6060	Describe emergency procedures for aircraft armament system malfunctions		X				X	X	
6061	Safe and clear weapon systems		X				X	X	

ATM #	TASK TITLE	UH-1	AH-1	OH-58	CH-47	UH-60	AH-64	AHIP SCOUT	TH-55
6063	Perform terrain flight firing techniques		X				X	X	
6065	Perform entry to and egress from firing positions		X				X	X	
6066	Acquire and identify targets	X	X	X	X	X	X	X	
6067	Engage targets by direct/ indirect fire	X	X	X	X	X	X	X	
6501	Perform after landing tasks	X	X	X	X	X	X	X	X
--	Operate IR jamming equipment	X	X	X	X	X	X	X	
--	Operate IHADDS/HDU						X		
--	Operate fire control computer (FCC)						X		
--	Operate Hellfire missile system						X		
--	Operate XM-230E1 (30mm) weapon system						X		
--	Perform PNVS operational checks						X		
--	Operate A/C using PNVS						X		
--	Perform TADS turn-on procedure						X		
--	Operate TADS						X		
--	Perform MMS operational check							X	
--	Operate MMS system							X	
--	Perform MFD/MFK operational check							X	
--	Operate MFD/MFK							X	
--	Operate MLMS							X	
--	Flight controls and instrument relationships								X
--	Flight controls								X
--	Anti-overspeed device								X
--	Perform simulated precautionary landing								X
--	Perform Frequency change procedure								X

A P P E N D I X B

TENTATIVE LISTING OF AHIP TASKS/CONDITIONS
TO BE USED IN DEFINING SIMULATOR
VISUAL SYSTEM REQUIREMENTS

ATM #	TASK	DAY UA[1]	DAY SENSORS[2] TV	DAY SENSORS IR	DAY SENSORS TS	DAY ENVIRONMENT[3] VMC CL	DAY ENVIRONMENT VMC RC	DAY ENVIRONMENT VMC RV	DAY ENVIRONMENT IMC	NIGHT UA	NIGHT SENSORS TV	NIGHT SENSORS IR	NIGHT SENSORS TS	NIGHT SENSORS LI	NIGHT ENVIRONMENT VMC CL H[4]	CL M[4]	CL L[4]	RC H	RC M	RC L	RV H	RV M	RV L	NIGHT ENVIRONMENT IMC	REMARKS
1001	Plan a VFR flight																								N/A
1002	Plan an IFR flight																								N/A
1003	Prepare DD Form 365F (Weight and Balance)																								N/A
1004	Use Performance Charts																								N/A
1005	Prepare Performance Planning Card (PPC)																								N/A
1501	Perform preflight inspection	X								X				X											
1502	Perform before takeoff checks	X				X	X	X		X					X	X	X	X	X	X	X	X	X		
2001	Perform takeoff to a hover	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
2002	Perform hover power check	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
2003	Perform hovering turns	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
2004	Perform hovering flight	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
2005	Perform landing from a hover	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
2501	Perform normal takeoff	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
2502	Perform simulated maximum performance takeoff	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
3001	Perform straight-and-level flight	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
3002	Perform (normal) climbs and descents	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
3003	Perform turns	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
3004	Perform deceleration/ acceleration	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
3005	Perform traffic pattern flight	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
3006	Perform fuel management procedures	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
3010	Perform navigation by pilotage and dead reckoning	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		

AIRCRAFT: AHIP SCOUT

[1] UA = UNAIDED

[2] SENSORS:
TV = TELEVISION
IR = INFRARED
TS = TELESCOPE
LI = LIGHT INTENSIFICATION (NIGHT ONLY)

[3] ENVIRONMENT:
CL = CLEAR
RC = REDUCED CEILING
RV = REDUCED VISIBILITY

[4] ILLUMINATION LEVEL:
H = HIGH
M = MEDIUM
L = LOW

AIRCRAFT: AHIP SCOUT		DAY								NIGHT															
			SENSORS[2]			ENVIRONMENT[3]					SENSORS				ENVIRONMENT										
						VMC									VMC										
															CL			RC			RV				
ATM #	TASK	UA[1]	TV	IR	TS	CL	RC	RV	IMC	UA	TV	IR	TS	LI	H[4]	M[4]	L[4]	H	M	L	H	M	L	IMC	REMARKS
3011	Perform doppler navigation	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
3501	Perform before landing checks	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
3502	Perform normal approach	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
3504	Perform shallow approach	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
3505	Perform steep approach	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
3506	Perform go-around	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
3510	Perform confined area operation	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
3511	Perform slope operation	X				X	X	X		X					X	X	X	X	X	X	X	X	X		
3512	Perform pinnacle/ridgeline operation	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
4001	Perform hovering autorotation	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
4002	Perform standard autorotation	X				X				X					X	X	X								
4003	Perform standard autorotation with 180° turn	X				X				X					X	X	X								
4004	Perform low-level autorotation	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
4005	Perform simulated hydraulic system malfunction	X				X	X	X		X					X	X	X	X	X	X	X	X	X		
4006	Perform simulated antitorque malfunction	X				X	X	X		X					X	X	X	X	X	X	X	X	X		
4008	Perform simulated engine failure at altitude	X				X				X					X	X	X								
4009	Perform simulated engine failure at a hover	X				X	X	X		X					X	X	X	X	X	X	X	X	X		
4010	Perform emergency procedures for actual or simulated NVG failure													X	X	X	X	X	X	X	X	X	X		
4019	Perform running landing	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
4021	Perform flight with SCAS/SAS/AFCS off	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
4026	Perform emergency procedures for emergency landing	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		

[1] UA = UNAIDED

[2] SENSORS:
TV = TELEVISION
IR = INFRARED
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[4] ILLUMINATION LEVEL:
H = HIGH
M = MEDIUM
L = LOW

AIRCRAFT: AHIP SCOUT		DAY								NIGHT															
		UA[1]	SENSORS[2]			ENVIRONMENT[3]				UA	SENSORS				ENVIRONMENT										REMARKS
						VMC			IMC						VMC									IMC	
															CL			RC			RV				
ATM #	TASK		TV	IR	TS	CL	RC	RV			TV	IR	TS	LI	H[4]	M[4]	L[4]	H	M	L	H	M	L		
4027	Perform emergency procedures for flight control system malfunction	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
4028	Perform emergency procedures for engine system malfunction	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
4029	Perform emergency procedures for fires	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
4030	Perform emergency procedures for fuel system malfunctions	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
4031	Perform emergency procedures for electrical system malfunction	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
4032	Perform emergency procedures for rotor, transmission, and drive train malfunctions	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
4501	Perform instrument takeoff	X*							X*	X*														X*	
4503	Perform radio navigation	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
4504	Perform holding procedure	X				X				X					X	X	X								
4505	Perform unusual attitude recovery	X				X	X	X		X					X	X	X	X	X	X	X	X	X		
4506	Perform radio communication procedures	X				X	X	X		X					X	X	X	X	X	X	X	X	X		
4508	Perform NAVAID approach	X				X	X	X		X					X	X	X	X	X	X	X	X	X		
4509	Perform ground controlled approach	X				X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	
4512	Perform tactical instrument takeoff	X							X	X														X	
4513	Perform tactical instrument approach	X							X	X								X	X	X	X	X	X	X	
5001	Perform terrain flight mission planning																								N/A
5002	Perform terrain flight navigation	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
5003	Perform low-level flight	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
5004	Perform contour flight	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		

[1]UA = UNAIDED

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AIRCRAFT: AHIP SCOUT		DAY								NIGHT																
			SENSORS[2]			ENVIRONMENT[3]					SENSORS				ENVIRONMENT											
						VMC									VMC											
															CL			RC			RV					
ATM #	TASK	UA[1]	TV	IR	TS	CL	RC	RV	IMC	UA	TV	IR	TS	LI	H[4]	M[4]	L[4]	H	M	L	H	M	L	IMC	REMARKS
5005	Perform nap-of-the-earth (NOE) flight	X								X				X	X	X	X	X	X	X	X	X	X		
5006	Perform masking/unmasking	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		
5007	Perform NOE deceleration	X				X	X	X		X					X	X	X	X	X	X	X	X	X		
5008	Perform out-of-ground-effect (OGE) hover check	X				X	X	X		X					X	X	X	X	X	X	X	X	X		
5009	Perform terrain flight takeoff	X				X	X	X		X					X	X	X	X	X	X	X	X	X		
5010	Perform terrain flight approach	X				X	X	X		X					X	X	X	X	X	X	X	X	X		
5011	Perform FM radio homing	X				X	X	X		X					X	X	X	X	X	X	X	X	X		
5012	Perform visual glideslope approach and landing									X					X	X	X	X	X	X	X	X	X		
5014	Perform tactical instrument flight planning																								N/A
5018	Perform evasive maneuvers	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
5019	Operate radar warning receiver AN/APR 39	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
5020	Perform ski landing	X				X	X	X		X					X	X	X	X	X	X	X	X	X		
5021	Perform preflight inspection of ski installation																								N/A
5022	Perform hover/taxi over snow	X				X	X	X		X					X	X	X	X	X	X	X	X	X		
5024	Perform techniques of movement	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		
5025	Identify US/allied and threat weapons and aircraft	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		
5030	Perform circling approach from terrain flight	X				X	X	X		X					X	X	X	X	X	X	X	[illegible]	[illegible]		
5033	Negotiate wire obstacles	X				X	X	X		X					X	X	X	X	X	X	X	X	X		
5035	Perform recognition of hazards to terrain flight	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		
5036	Perform as a crew member (cockpit teamwork)	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		

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AIRCRAFT: AHIP SCOUT		DAY								NIGHT																
			SENSORS[2]			ENVIRONMENT[3]					SENSORS				ENVIRONMENT											
						VMC									VMC											
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ATM #	TASK	UA[1]	TV	IR	TS	CL	RC	RV	IMC	UA	TV	IR	TS	LI	H[4]	M[4]	L[4]	H	M	L	H	M	L	IMC	REMARKS
5100	Operate communications equipment																								N/A
5106	Operate chaff dispenser																								N/A
6016	Perform target handoff to attack helicopters																								N/A
6044	Supervise installation and loading of weapons																								N/A
6045	Preflight aircraft weapon systems																								N/A
6049	Perform weapons cockpit procedures																								N/A
6060	Describe emergency procedures for aircraft armament system malfunctions																								N/A
6061	Safe and clear weapon systems																								N/A
6063	Perform terrain flight firing techniques	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		
6065	Perform entry to and egress from firing positions	X	X		X	X	X	X		X	X		X	X	X	X	X	X	X	X	X	X	X		
6066	Acquire and identify targets	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		
6067	Engage targets by direct/ indirect fire	X	X		X	X	X	X		X	X		X	X	X	X	X	X	X	X	X	X	X		
6501	Perform after landing tasks	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
	Operate IR jamming equipment	X				X	X	X		X				X	X	X	X	X	X	X	X	X	X		
	Perform MMS operational check	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		
	Operate MMS system	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		
	Perform MFD/MFK operational check																								N/A
	Operate MFD/MFK																								N/A
	Operate MLMS	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		

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Technical Report 763

An Enumeration of Research to Determine the Optimal Design and Use of Army Flight Training Simulators

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Anacapa Sciences, Inc.
and
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U. S. Army

Research Institute for the Behavioral and Social Sciences

October 1987

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Anacapa Sciences, Inc

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Charles A. Gainer, Contracting Officer's Representative

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Army Flight Simulator Research Requirements
Helicopter Pilot Training
Transfer-of-Training
Backward Transfer
Flight Simulator Fidelity Requirements
Training Device Characteristics
Flying Skill Acquisition
Flying Skill Sustainment
Training Device Requirements
Training Effectiveness Assessment

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This documents lists and describes research the authors judged necessary to determine the optimal design and use of Army flight training simulators. Two major lines of research are described. The first ~~line of research~~ addresses the design fidelity issue. Specifically, research is described that is judged necessary to determine the most cost and training-effective level of fidelity for four simulator components: the visual system, the motion systems, the math models that determine the handling qualities of the flight simulator, and the

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~~BLOCK~~ 20. ABSTRACT Continued

cockpit displays and controls. The purpose of the second line of research is to determine how best to use production simulators~~--simulators~~ that have been or are soon to be acquired by the Army. This line of research focuses primarily on the use of production simulators for field unit aviators--~~aviators~~ who have completed institutional training and have been assigned to an operational field unit. However, the second line of research addresses some issues associated with the use of flight simulators for institutional training~~--training~~ at the U. S. Army Aviation Center received before ~~prior to~~ the aviator's first assignment to an operational unit.

This document was prepared to serve as a vehicle for initiating meaningful dialogue among the agencies and personnel who share responsibility for optimizing the benefits of the Army's Synthetic Flight Training System (SFTS) program; it has not been officially endorsed by any Army agency.

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Technical Report ~~ASI479-066-85~~

AN ENUMERATION OF RESEARCH TO DETERMINE
THE OPTIMAL DESIGN AND USE OF ARMY
FLIGHT TRAINING SIMULATORS

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Office, Deputy Chief of Staff for Personnel
Department of the Army

~~February 1985~~
OCTOBER 1987

Army Project Number
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~~Simulation Systems Design~~
Training and Simulation

FOREWORD

The Army is committed to the use of flight simulators to augment the training that Army helicopter pilots receive in the helicopter itself. The most important reasons for this commitment are discussed in the main body of the report. For now, it is sufficient to say that the use of flight simulators to augment aircraft training is the only means, during peacetime, of achieving the level of operational readiness that is desired at a cost ~~that is~~ acceptable. Until now, nearly all the resources expended by the Army on its Synthetic Flight Training System (SFTS) program have been aimed at hardware development and acquisition. The resources devoted to research on how best to use flight simulators is miniscule by comparison. Hence, it is not surprising that there are a large number of uncertainties about the specific role of flight simulators in the Army's aviator training program. It is worth noting that these uncertainties are not unique to the Army; both the Air Force and Navy are faced with much the same problems.

In preparing this document, the authors and contributors attempted to be thorough in identifying critical research issues. Also, to the extent possible with the time and resources available, an attempt was made to develop research plans that address the issues in a meaningful and practical way. We feel confident that the research issues identified are relevant ~~and non-trivial~~. However, we do not consider the research plans presented in this document to be the only way or, necessarily, the best way to deal with the issues identified. When developing long-term research on a topic ~~for~~ which so little is known, it must be expected that the results of earlier research may drastically change one's early views about the best way to proceed. In short, the plans for later stages of the research must be considered tentative and subject to change, based upon the findings of earlier research.

It can be argued that plans for research on such a difficult topic should proceed in a step-by-step fashion. Indeed, ~~the step-by-step~~ approach is much less threatening to the research planner who must formulate ~~research~~ plans that are based upon premises several levels removed from any empirical data. Also, this approach is less likely to portray to decision makers a research requirement that initially appears overwhelmingly complicated and costly. The disadvantages of the step-by-step approach, which we feel far offset the advantages, are twofold. First, a great deal of time and research continuity would be lost if efforts to obtain funding and administrative support for the next research stage are not commenced until the results of the preceding stage have been fully analyzed and documented. A hiatus between each stage of research would probably serve to make a difficult job impossible. Second, a general notion of the scope of the research is needed to make sensible decisions about whether or not to embark on the research and, if an affirmative decision is made, to make sensible decisions about how best to marshal the resources needed to continue the research until truly useful results are in hand. For these reasons, we have decided that relatively detailed long-term plans--even imperfect ones--serve an important purpose.

The intent is that this document serve as a beginning of dialogue among the agencies and personnel who share responsibility for optimizing the benefits of the Army's SFTS program. It is hoped that this dialogue, in turn, will lead to the refinement of ideas, to the establishment of research priorities, and to joint planning by all involved agencies. It is important that the reader keep in mind that this is not a document ~~that is~~ being submitted for approval or disapproval, in total or in part. For this reason, feedback from readers about flaws in the premises and/or reasoning are welcomed. Comments should be sent to Mr. Charles A. Gainer at the following address:

Chief
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Attn: PERI-IR (Mr. Charles A. Gainer)
Fort Rucker, AL 36362-5354

EDGAR M. JOHNSON
Technical Director

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Many members of the Army Research Institute (ARI) staff and the Anacapa Sciences, Inc., (ASI) staff made major contributions to this document. Some contributions consisted of careful critiques of draft versions of the document. These contributions are indeed important and are gratefully acknowledged. The contributions of others were even more substantive. Many of the ideas presented in this document resulted directly from information and insights gained from detailed discussions with ARI and ASI personnel. Some individuals presented valuable information and useful ideas in writing. Listed below, in alphabetical order, are individuals whose ideas and words were used extensively in preparing the final version of this document:

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- Dr. Dennis H. Jones (ASI)
- Dr. George L. Kaempf (ASI)
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- Mr. Steven L. Millard (ASI)
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- Dr. Brian D. Shipley (ARI)
- Dr. Robert H. Wright (ARI)

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Finally, it is important to acknowledge that many of the ideas originated from reports and articles found in the open literature. Although care has been taken to give credit to the individuals whose work was drawn upon, there is one effort that deserves special acknowledgment. The series of seven STRES (Simulator Training Requirements and Effectiveness Study) reports, prepared under the sponsorship of the Air Force Human Resources Laboratory, contained an enormous amount of information that was ~~found~~ useful in clarifying research issues and formulating ~~research~~ plans. The authors of the STRES reports are commended for the quality and thoroughness of their work.

AN ENUMERATION OF RESEARCH TO DETERMINE THE OPTIMAL DESIGN AND USE OF ARMY FLIGHT TRAINING SIMULATORS

EXECUTIVE SUMMARY

The purpose of this document is to identify the types of research ~~that are~~ needed to determine the optimal design and use of Army flight simulators. Two complementary lines of research are described and discussed. One line of research--referred to as the "Long-Term Path"--focuses primarily on simulator design issues. The primary focus of the second line of research--the "Short-Term Path"--is the determination of the best way to use the flight simulators that have been or are soon to be acquired by the Army.

LONG-TERM PATH

The general objectives of the Long-Term Path--formulated by the Assistant Secretary of the Army for Research, Development, and Acquisition--are as listed below:

- design research that will yield the data needed to quantify the relationship between fidelity (in selected flight simulator design parameters) and training transfer (for selected flying tasks),
- design research that will yield the data needed to define the relationship between flight simulator production costs and required fidelity in the selected flight simulator design parameters, and
- design research to define the type, cost, and effectiveness of alternate training methods and media that could be used in lieu of flight simulators to train one or more of the selected flying tasks.

In response to the general research objectives, requirements for research were defined for five "primary" research areas and nine "supportive" research areas. The primary research areas are:

- fidelity requirements for visual system,
- fidelity requirements for motion system,
- fidelity requirements for simulator handling qualities,
- fidelity requirements for cockpit displays and controls, and
- requirements for simulator Instructional Support Features.

The supportive research areas are topical areas for which there are problems or uncertainties that must be resolved in order to conduct effective research in the primary research areas. Supportive research areas identified and discussed include:

- flying task data base,
- team/combined-arms training methods,
- performance evaluation,
- alternative training media,
- subsystem standardization/modularization,
- research methodology,
- skill decay/maintenance,
- implementation/monitoring of simulator training, and
- cost-effectiveness analysis models.

The discussion of each of the above research areas includes a description of the research issues and objectives, comments about relevant research that has been reported in the literature, and a description of the research considered necessary to resolve the issues. The research plans vary widely in detail and complexity.

SHORT-TERM PATH

The Short-Term Path is a program of research that is aimed at evaluating and optimizing the use of the family of flight simulators that the Army already has acquired or has contracted to purchase. Since the design of this family of simulators is more or less fixed, the research is focused mainly on determining how best to use the devices: who should be trained, what tasks should be trained, how much training should be administered, and what training methods should be employed for each training application. A secondary objective of the Short-Term Path is to identify design modifications (hardware and/or software) that will improve the training effectiveness of production simulators without incurring excessive product improvement costs.

Three major research efforts are described. The objective of the first research effort is to determine the optimal use of flight simulators in a unit-training context. (Unit training refers to the training received by Army aviators after they have completed institutional training and have been assigned to an operational unit.) The research is designed to assess the simulator's utility for five different training applications: refresher training, skill sustainment training, skill enrichment training, accident prevention training, and maintenance test-pilot training.

The objective of the second research effort is to evaluate the simulator's utility for training beginning students in the fundamentals of helicopter operation. A three-phase study is described that addresses both simulator design issues and training methodology issues. If the early work supports the feasibility of the concept, transfer-of-training studies will be conducted to determine the optimal mix of simulator training and aircraft training.

The objective of the third research effort is to determine the extent to which Night Vision Goggle training can be accomplished in a flight simulator equipped with a visual system.

AN ENUMERATION OF RESEARCH TO DETERMINE THE OPTIMAL DESIGN AND USE OF ARMY FLIGHT TRAINING SIMULATORS

GLOSSARY OF ACRONYMS

AAA	- Army Audit Agency
AFHRL	- Air Force Human Resources Laboratory
AGARD	- Advisory Group for Aerospace Research and Development
AGL	- Above Ground Level
AH	- Attack Helicopter
AHIP	- Army Helicopter Improvement Program
ANVIS	- Aviator's Night Vision Image System
AOI	- Area of Interest
AQC	- Aviation Qualification Course
ARI	- U.S. Army Research Institute for the Behavioral and Social Sciences
ARL	- Aviator Readiness Level
ARTEP	- Army Training and Evaluation Program
ASI	- Anacapa Sciences, Inc.
ASPT	- Advanced Simulator for Pilot Training
ATM	- Aircrew Training Manual
BOIP	- Basis of Issue Plan
CAPTV	- Computer Animated Photographic Terrain View
CGSI	- Computer-Generated/Synthesized Imagery
CH	- Cargo Helicopter
CIG	- Computer-Image Generation
CMB	- Camera-Modelboard
CRT	- Cathode Ray Tube
CTEA	- Cost and Training Effectiveness Analysis
DARCOM	- Development and Readiness Command
DES	- Directorate of Evaluation and Standardization
DLS	- Digital Landmass System
DMA	- Defense Mapping Agency
DOD	- Department of Defense
FLIR	- Forward-Looking Infrared
FOV	- Field-of-View
FS	- Flight Simulator
HUD	- Head-up Display
IC	- Initial Conditions
IERW	- Initial Entry Rotary Wing
IFR	- Instrument Flight Rules
IGE	- In-Ground Effect
ILS	- Instrument Landing System
IMC	- Instrument Meteorological Conditions
IP	- Instructor Pilot
IPR	- In-Process Review
IR	- Infrared

ISF	-	Instructional Support Features
LOD	-	Level of Detail
MASSTER	-	Modern Army Selected System Test, Evaluation, and Review
MOPP	-	Mission Oriented Protective Posture
MTFE	-	Maintenance Test Flight Evaluator
MTP	-	Maintenance Test Pilot
NBC	-	Nuclear, Biological, Chemical
NOE	-	Nap of the Earth
NTEC	-	Naval Training Equipment Center
NVG	-	Night Vision Goggles
OGE	-	Out-of-Ground Effect
PIC	-	Pilot in Command
POI	-	Program of Instruction
PMTRADE	-	Project Manager Training Devices
RSIS	-	Rotorcraft System Integration Simulator
SFTS	-	Synthetic Flight Training System
SME	-	Subject Matter Expert
STRES	-	Simulator Training Requirements and Effectiveness Study
TC	-	Training Circular
TH	-	Training Helicopter
THIESIS	-	Training Helicopter Initial Entry Students in Simulators
TOE	-	Tables of Organization and Equipment
TRADOC	-	Training and Doctrine Command
UH	-	Utility Helicopter
USAALS	-	U.S. Army Aviation Logistics School
USAAVNC	-	U.S. Army Aviation Center
VFR	-	Visual Flight Rules
VTRS	-	Visual Technology Research Simulator

AN ENUMERATION OF RESEARCH TO DETERMINE THE OPTIMAL DESIGN AND USE OF ARMY FLIGHT TRAINING SIMULATORS

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